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Sea King SHOL Support for Post-HCM/FELEX HALIFAX Class Ships

Sea Trial Summary: HMCS FREDERICTON December 2-9, 2013

Eric Thornhill

Defence Research and Development Canada

Scientific Report
DRDC-RDDC-2014-R18
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Abstract

The Halifax Class frigates are in the process of a mid-life modernization. The engineering changes made to the ships during the refit have resulted in significant superstructure modifications affecting both the airwake over the flight deck and the accuracy of the mast-mounted anemometer system. This requires that the CH124 Sea King Ship-Helicopter Operational Limits (SHOL) envelope be re-certified for operation from post-refit ships. This re-certification will involve extensive wind tunnel experiments conducted by the National Research Council (NRC) in addition to a limited sea trial program. This report summarizes DRDC's contribution to the sea trial conducted on HMCS FREDERICTON in December 2013 that was part of this effort. The ship was instrumented with supplementary anemometers at the bow and mast to help validate the wind tunnel experiments. Aircraft operations were conducted by Aerospace Engineering Test Establishment (AETE) as part of the SHOL development with support from the prototype Flight Deck Motion System (FDMS) developed by DRDC Atlantic. Analysis and interpretation of the resulting data set is presented in separate reports by AETE and NRC.

Significance for defence and security

The Halifax Class frigates are in the process of a mid-life modernization. The engineering changes made to the ships during the refit have resulted in significant superstructure modifications affecting both the airwake over the flight deck and the accuracy of the mast-mounted anemometer system. These changes invalidate the CH124 Sea King Ship-Helicopter Operational Limits (SHOL) envelope established for the baseline Halifax Class. To ensure that the Royal Canadian Navy (RCN) and Royal Canadian Air Force (RCN) could continue to deploy ships with an embarked helicopter in order to meet Canada's strategic and operational objectives and commitments, it became essential to provide a CH124 Sea King shipborne capability following the Halifax Class refit. The operational capability is required by April 2014 to meet the current RCN deployment schedule for the first high readiness post refit ship. Aerospace Engineering Test Establishment (AETE) was tasked by 1 Canadian Air Division to conduct SHOL testing to define the HCM/CH124 operating envelope. AETE then tasked DRDC Atlantic and the National Research Council (NRC) to support this effort.

Résumé

Les frégates de classe Halifax connaissent une modernisation de mi-durée. Les modifications techniques apportées aux navires pendant le radoub ont entraïné des changements importants à la superstructure qui ont une incidence sur le sillage au dessus du pont d'envol et sur la précision de l'anémomètre fixé au mât. Cela nécessite que la fourchette des limites opérationnelles des navires hélicoptères (LONH) du CH124 Sea King soit recertifiée pour une utilisation à partir des navires après raboud. Cette recertification donnera lieu à des expériences poussées en tunnel aérodynamique effectuées par le Conseil national de recherches (CNRC) en plus d'un programme limité d'essais en mer . Le présent rapport résume la contribution de RDDC à l'essai en mer effectué sur le NCSM FREDERICTON en décembre 2013 qui faisait partie de cet effort. Le navire était muni d'anémomètres supplémentaires à la proue et au mât pour aider à valider les expériences réalisées en tunnel aérodynamique. Le Centre d'essais techniques (aérospatiale) (CETA) utilisait des aéronefs dans le cadre du développement des LONH avec un soutien du prototype de système d'aide à l'appontage mis au point par RDDC Atlantique. L'analyse et l'interprétation de l'ensemble des données résultantes sont présentées dans des rapports distincts par le CETA et le CNRC.

Importance pour la défense et la sécurité

Les frégates de classe Halifax connaissent une modernisation (MCH) de mi-durée. Les modifications techniques apportées aux navires pendant le radoub ont entraïné des changements importants à la superstructure qui ont une incidence sur le sillage au dessus du pont d'envol et sur la précision de l'anémomètre fixé au mât. Ces modifications invalident la fourchette des limites opérationnelles des navires hélicoptères (LONH) du CH124 Sea King établie pour la classe Halifax de référence. Afin de s'assurer que la Marine royale canadienne (MRC) et l'Aviation royale canadienne (ARC) puissent continuer à déployer des navires avec un hélicoptère embarqué pour respecter les engagements et les objectifs opérationnels et stratégiques du Canada, il est devenu essentiel de fournir une capacité embarquée de CH124 Sea King à la suite du radoub de la classe Halifax. La capacité opérationnelle est nécessaire au plus tard en avril 2014 pour respecter le calendrier de déploiement actuel de la MRC pour le premier navire après radoub à haut niveau de préparation. Le Centre d'essais techniques (aérospatiale) (CETA) a été chargé par la 1ère Division aérienne du Canada de procéder à des essais LONH pour définir la fourchette d'utilisation du CH124/HCM. Le CETA a ensuite chargé RDDC Atlantique et le Conseil national de recherches (CNRC) d'appuyer cet effort.

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1 Introduction

The HALIFAX Class Frigates are undergoing a mid-life refit managed under the Halifax Class Modernization (HCM)/Frigate Life Extension (FELEX) project. The modernization of the ships will include the implementation of new capabilities into the ships that are required to meet new threats and changing operating environments, as well as maintenance and sustainment work needed to keep equipment at its current level of capability [1].

The FELEX/HCM refit involves two changes that are expected to be relevant for shipboard helicopter operations. The first is the movement of the ship anemometers on the main mast along with the addition of large aerodynamically bluff equipment to the mast structure in the vicinity of the anemometers. This change is expected to affect the apparent wind sensed by the ship's anemometers and will result in an apparent shift of the CH124 SHOL envelope (in wind speed, wind direction, or both). The second is the addition of two large Protected Military Satellite Communication (PMSC) domes on either side of the hangar structure. These structures may change the Wind Over Deck (WOD) sufficiently to affect the SHOL envelope for some relative wind directions.

To ensure that the RCN/RCN can continue to deploy ships with an embarked helicopter to meet Canada's strategic and operational objectives and commitments, it has become essential to provide a CH124 Sea King shipboard capability following the HCM/FELEX project. This capability is required no later than the spring of 2014 to meet the current RCN deployment schedule for the first high readiness HCM. First Canadian Air Division has tasked Aerospace Engineering Test Establishment (AETE) with redefining an appropriate SHOL for the HCM/CH124 ship-helicopter pair, and AETE in turn partnered with the National Research Council (NRC) and Defence Research and Development Canada (DRDC) Atlantic to leverage modern simulation tools, developed under the SHOLAS effort, to guide the test matrix for the at-sea SHOL trial. This partnership is intended to reduce the time and cost associated with a full legacy method sea trial[1].

This report summarizes the activities involved with the preparation and execution of a dedicated SHOL sea trial on HMCS FREDERICTON with aircraft CH124-412 conducted on December 2-9, 2013 off the coast of Nova Scotia.

[1] This method involves conducting a lengthy series of flight tests in conditions incrementally increasing in difficulty.

Figure 1: Sea King 412 on HMCS FREDERICTON

1.1 Objectives

The main objectives of this sea trial were to:

a. Collect wind data from both the ship's mast-mounted and trial-fit anemometers in order to quantify the speed & direction biases of the ship's anemometers resulting from the Engineering Changes (ECs) made to the mast;

b. Conduct SHOL flight and other activities in accordance with the AETE test plan;

c. Collect data from the helicopter using the trial-fit acquisition equipment for analysis and validation of SHOL assessment methodologies; and

d. Collect data from the ship using the trial-fit acquisition equipment for analysis of validation of the FDMS.

1.2 SHOLAS

The HCM/CH124 re-certification is relying on work being done in the SHOL Analysis and Simulation (SHOLAS) Research and Development (R&D) project. This project, a collaborative effort of DRDC, NRC, and DND, was created specifically to meet the needs of the Major Capital Projects (MCPs) with respect to helicopter operations. One of the major outcomes of SHOLAS used for CH124/HCM re-certification is the SHOL Assessment

Methodology (SAM), which consists of modelling tools, analysis procedures, and expertise that allow the modelling of different ship-helicopter pairings and the resulting operational envelopes.

Fundamentally, SAM seeks to model the system shown in Figure 2. First, a given ship topsides geometry creates an airwake flowfield which can be influenced by the atmospheric boundary layer (ambient wind condition) and ship motions. This relationship is marked as 1, and is typically simulated either numerically with Computational Fluid Dynamics (CFD), or experimentally using wind tunnel modelling. Once a helicopter is introduced to the airwake, the rotor downwash modifies it, and the resulting flowfield acts on the helicopter rotor and fuselage with unsteady loading. This relationship, marked as 2, is more complex. The resulting unsteady loading propagates through the helicopter control system and the pilot, ultimately resulting in a difficulty rating being assigned for the given ship and wind condition. This rating leads to the published operational limits for the aircraft. The relationship between unsteady loading and operational limits is marked as 3, and contains the effects of the helicopter control system and pilot inputs.

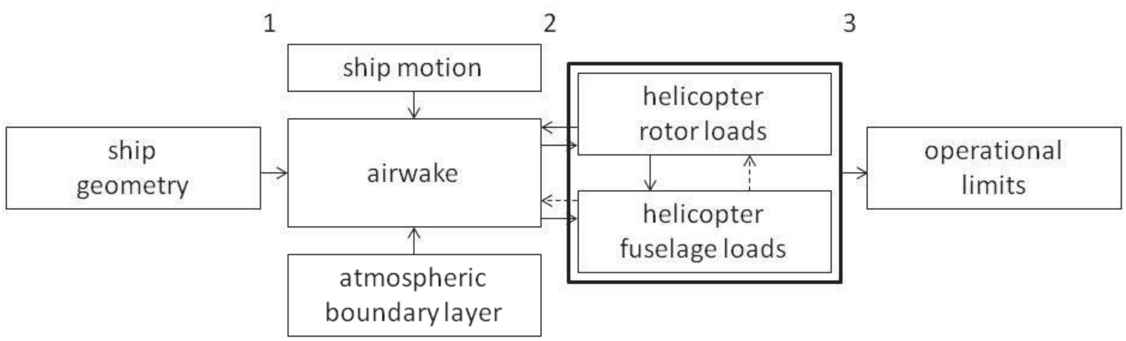

Figure 2: Simulation components for the ship-helicopter interface

SAM seeks to identify a suite of modelling tools, evaluation methods, and expertise to correlate the airwake and helicopter unsteady loading with the resulting operational limits. In this way, quantities that can be simulated, such as airwake and aircraft loading, can be used to evaluate operational limits. The current version of SAM is described in detail in [2, 3].

The ECs made to the ship that are of concern for airwake and wind measurement are shown in Figure 3 for the masts in isolation, and Figure 4 which shows models of the ships topsides. Figure 5 shows the post-refit model during one of the wind tunnel tests conducted at NRC. The probes in this figure are in the same positions as the anemometers used in this sea trial. Figure 6 shows one of the tests with the model ship and model Sea King with active rotor.

Figure 3: Ship mast before and after refit

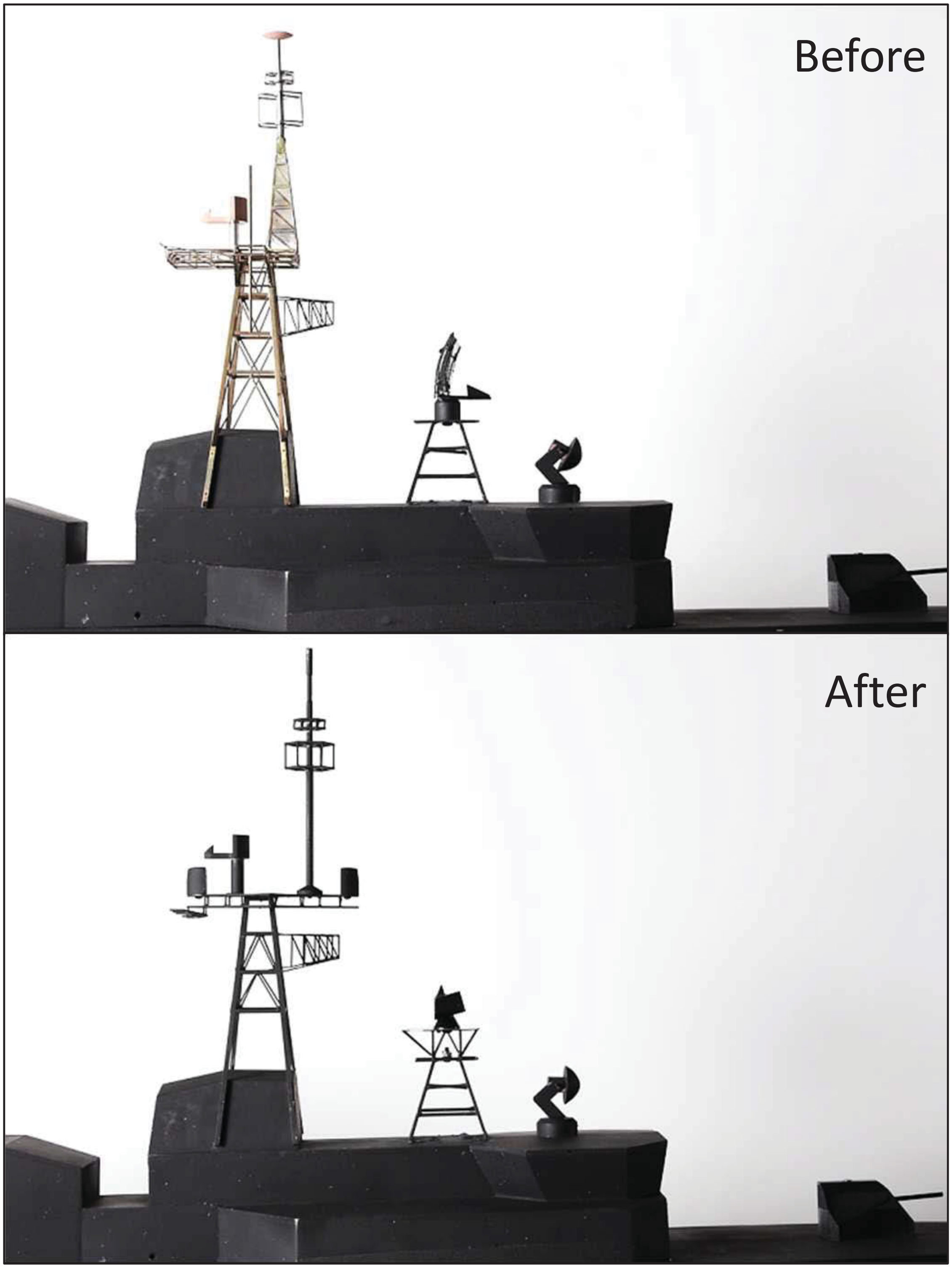

Figure 4: Ship topsides before and after refit

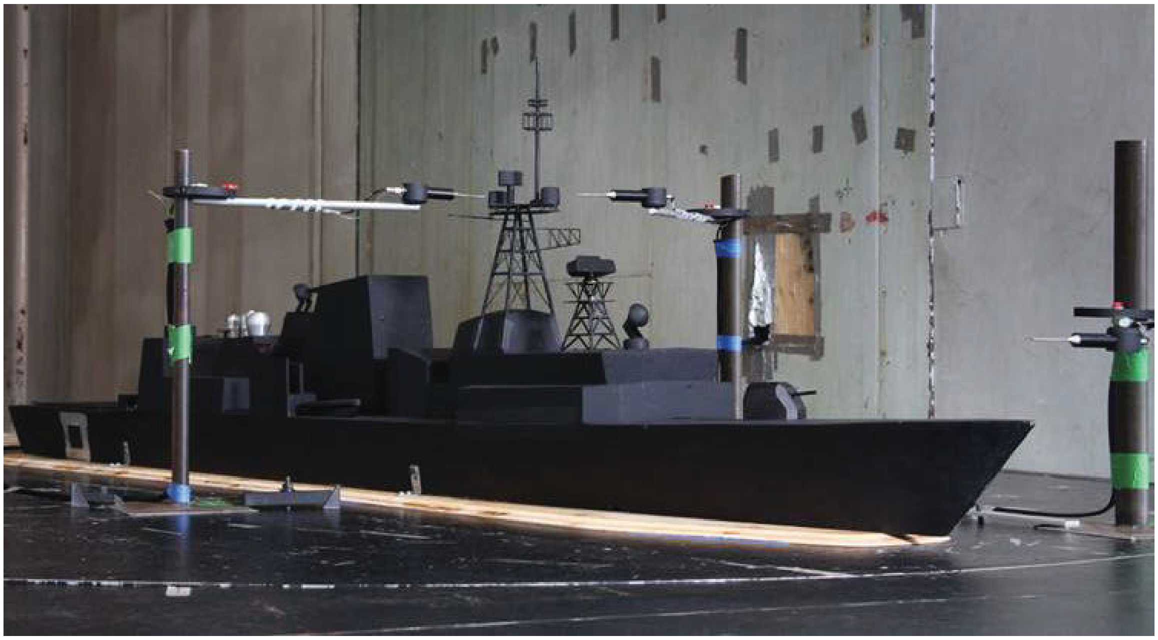

Figure 5: Post-refit model ship

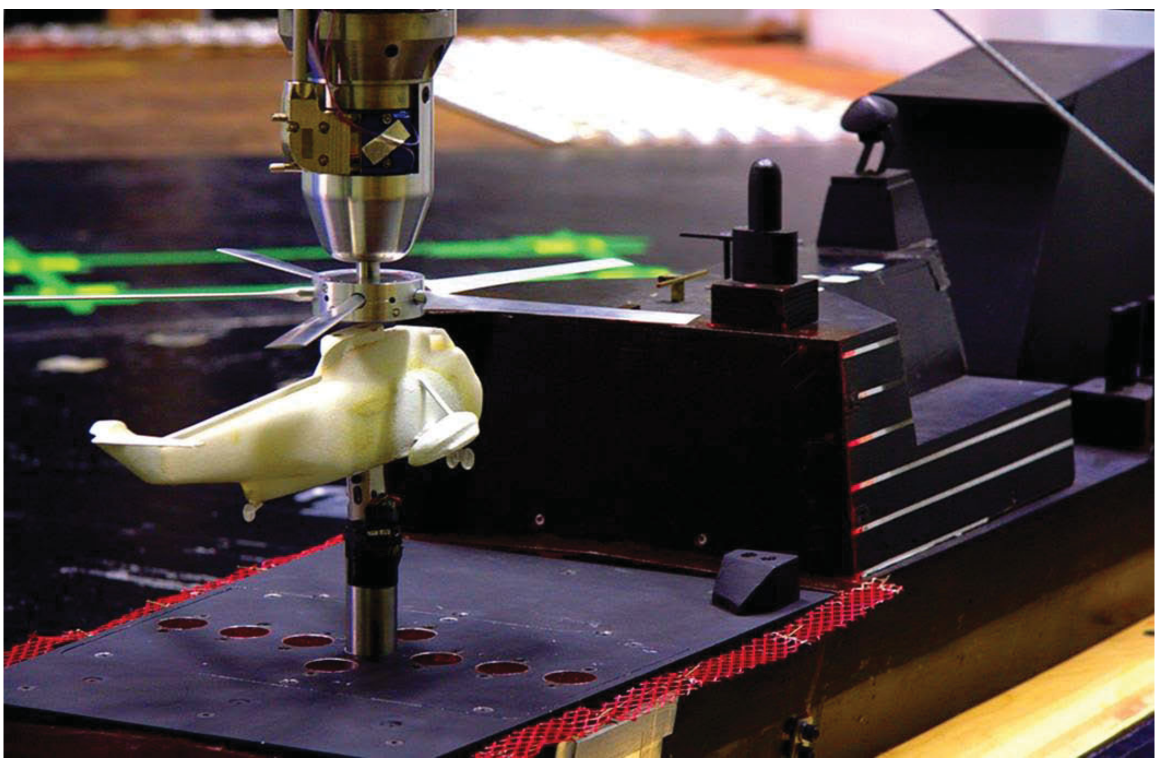

Figure 6: Model test with helicopter & active rotor

2 Instrumentation and data collection

There were two Data Acquisition (DAQ) systems used on the trial; the aircraft DAQ and the ship DAQ. The aircraft DAQ was developed and managed by AETE and will not be discussed here (AETE will produce a separate report discussing the aircraft instrumentation and flight test results). The ship DAQ was developed by DRDC with input from NRC and AETE to provide data such as wind speed & direction, ship speed, heading, and motions.

The ship DAQ components were distributed about the ship at the bow, mast, port bridge wing, port breezeway, howdah (a.k.a. LSO compartment), Flyco (a.k.a. FDCR), Air Detachment Room (ADR), hanger face, flight deck, and Aft SIS. In order to provide the real-time data feeds required by the FDMS (see Section 3), these systems were connected together using an independent stand-alone DRDC network. The only connection to any ship network was to log NDDS data (see Section 2.1). Table 1 summarizes the acquired data sets and Table 2 gives the sensor positions on the ship.

Due the nature of the some of the instrumentation, parts of the installation were conducted by the Fleet Maintenance Facility Cape Scott (FMF Cape Scott) through a temporary EC issued by AETE with input from DRDC. Changes were reversed after the trial was complete. These included installation of:

- Optical-fibre network cable from Flyco to Aft SIS;
- Optical-fibre network cable from ADR to Aft SIS;
- Optical-fibre network cable from bridge wing to Aft SIS;
- LGS display mount to top of hanger;
- Conductor cable from Flyco to hanger top (for LGS);
- Two RG-59 cables from howdah to Aft SIS;
- Video cable from howdah to Aft SIS;
- Cat-5 cable from howdah to Aft SIS;
- Video camera mounts (one on top of hanger and two on starboard side of flight deck)
- Video cables from three video cameras to Flyco (two cameras on starboard side of flight deck, one on hanger top);
- NAV420 mounting bracket in Aft SIS;
- FDMS display mounting bracket in howdah;
- Mounting brackets for displays and miscellaneous equipment in Flyco;
- Installation of anemometer and support in mast; and
- Conductor cable from mast anemometer to bridge wing.

The rest of the instrumentation was installed by DRDC personnel. A trial fit-out was conducted on November 18-21, 2013. The final fit-out was conducted November 28-29, 2013.

Table 1: Trial measurements

Measurement	Units	Data Rate	Section Reference
Date and Time	UTC	1 Hz	2.1 2.4
Ship Location	Lat,Long	1 Hz	2.1
Ship Speed	knots	1 Hz	2.1
Ship Course	deg (true)	1 Hz	2.1
Ship Heading	deg (true)	1 Hz	2.1
Ship Roll	deg	20 Hz	2.3
Ship Pitch	deg	20 Hz	2.3
Flight Deck Vertical Acceleration	m/s^2	20 Hz	2.3
Flight Deck Lateral Acceleration	m/s^2	20 Hz	2.3
Flight Deck Longitudinal Acceleration	m/s^2	20 Hz	2.3
Bow Vertical Velocity	m/s	20 Hz	2.8
Air Temperature	°C	1 Hz	2.1, 2.6
Barometric Pressure	Pa	1 Hz	2.1, 2.6
Relative Humidity	%	1 Hz	2.1, 2.6
Relative Wind Speed	knots	1 Hz	2.1, 2.6
Relative Wind Direction	deg	1 Hz	2.1, 2.6
Sea State	-	Twice Daily	2.5

Table 2: Instrument locations (approximate)

Instrument	X [m]	Y [m]	Z [m]
NAV420 Motion Sensors	19	0	16.5
NRC 3m Bow Anemometer	132	0	15.8
NRC 5m Bow Anemometer	132	0	17.8
NRC Mast Anemometer	88	0	28.5
Port Starlight GPS Antenna	96.7	5.5	18.75
Starboard Starlight GPS Antenna	96.7	-5.5	18.75
Ship Port Anemometer	81	3.75	28.5
Ship Starboard Anemometer	81	-3.75	28.5
Ship GPS Reference Location	59.63	0.02	6.56
AETE Forward Flight Deck Camera	13	-7	11
AETE Aft Flight Deck Camera	6.5	-7	11
AETE Hanger Face Camera	29	-1	29
NRC Meteorological Sensors	79	7	16.75

Longitudinal X is relative to the AP. Lateral Y is relative to the ship centreline (port is positive, starboard is negative). Vertical Z is relative to the baseline (keel). The AP is defined at the intersection of the transom with the waterline at a level draft of 5.00m.

2.1 NDDS logging

The Navigational Data Distribution System (NDDS) is used to provide various navigational and environmental data streams throughout the ship [4]. Data such as wind speed from the ship's anemometers as well as ship speed and heading were essential for the execution of this trial.

Connection to the ship's NDDS system was complicated by the fact it is a SECRET network, even though the specific data required from the system was not classified. This unclassified data had to be moved from a classified network to an unclassified network in such a way as to not compromise the security of the classified network. This was achieved by using a configuration which permitted only one-way communication of selected data from the NDDS to the DRDC network, as described in Section 2.10.

The following data streams were logged through NDDS port 14041:

a. `$GPVTG` - Course and speed;
b. `$INVHW` - Heading and Speed Through Water (STW)
c. `$INVTG` - Course Over Ground (COG) & Speed Over Ground (SOG)
d. `$INXDR` - Heading, roll, pitch
e. `$GPGGA` - GPS position & time

f. `$INHDT` - Ship heading
g. `$INROT` - Ship rate of turn
h. `$INGLL` - Latitude and Longitude[2]
i. `$INZDA` - GPS date & time
j. `$WIMTW` - Water temperature
k. `$SDDBT` - Water depth below transducer
l. `$PAXDR` - Air temperature, pressure, and humidity
m. `$SDDPT` - Water depth and offset
n. `$P1MWV` - Port anemometer apparent wind & angle
o. `$P2MWV` - Port anemometer true wind speed & angle
p. `$P2MWD` - Port anemometer true wind speed & direction
q. `$P3MWV` - Stbd anemometer apparent wind & angle
r. `$P4MWV` - Stbd anemometer true wind speed & angle
s. `$P4MWD` - Stbd anemometer true wind speed & direction

During preparations for the trial, it was not clear whether all required data streams would be available through port 14041 or whether some streams would need to be acquired from port 14001. Therefore a duplicate NDDS logging system was used to log port 14001. Once the initial set-up was tested on the ship in late November, it was determined that port 14041 did indeed have all the required data streams. Port 14001 was stilled logged during the trial, but this data was not broadcasted to the DRDC network, processed, or otherwise used for analysis.

The following sentences were logged through port 14001:

a. `$INVHW` - Heading and Speed Through Water (STW)
b. `$INVTG` - Course Over Ground (COG) & Speed Over Ground (SOG)
c. `$INXDR` - Heading, roll, pitch
d. `$INGLL` - Latitude and Longitude
e. `$INZDA` - GPS date & time
f. `$INHDT` - Ship heading
g. `$INROT` - Rate of turn
h. `$GPVTG` - Ship rate of turn
i. `$GPGSA` - GPS Dilution of Precision (DOP)
j. `$GPGGA` - GPS position & time

[2] Position data are with respect to the ship GPS reference location as defined in Table 2.

2.2 IPMS logging

The IPMS (also known as Halifax Class IPMS or HCI) was used to log various data streams related to the machinery and propulsion systems during the trial. The following data was transferred to the DRDC team at the end of the trial.

a. Shaft RPM (port & starboard);
b. Propeller pitch setting (port & starboard);
c. Gas Turbine (GT) Power Level Angle (PLA) (port & starboard);
d. Shaft torque (port & starboard);
e. Shaft power (port & starboard); and
f. Drive mode.

2.3 Ship motion sensors

Ship motions were recorded using DRDC Atlantic's NAV420CA-100 (Crossbow Technologies Inc.) Inertial Measurement Unit (IMU) motion sensors. The sensor uses angular rate sensors, linear accelerometers, and magnetometers on each of the three principal axes (x, y, and z) to calculate and output dynamic motions in 6 Degrees of Freedom (DOF).

The NAV420 operates in one of three modes: Scaled Sensor Packet, Angle Packet, or NAV Packet (default on start-up). It is standard practice to use Angle Packet mode for sea trials as it gives output in the most usable form (angles, angular rates, & accelerations). Angular displacements (roll, pitch, yaw) are not measured directly, but are calculated by integrating angular rates. Due to the fact that rate sensors suffer from drift errors, a correction procedure (Kalman filter) is required to produce stabilized angle output. The NAV420 performs this correction using one of two algorithms depending on whether or not the unit is connected to a GPS [5]. Though not always possible in a ship installation, connection to a GPS is the preferred arrangement.

Two units were installed on a custom-fitted bracket in Aft SIS as shown in Figure 7. Both units were logged continuously, and the FDMS system was configured so that it could read from either sensor with the push of a button. Figure 8 shows the orientation of the sensors as installed with the mounting plates down and the connectors facing forward towards the bow. The unit on the port side (serial #0005012941) was typically used as the primary data source while the unit on the starboard side (serial #0701004804) was the backup. The units were connected to a GPS, but the location of the antenna (in the window of the howdah) meant that it had a limited view of the sky and may not always have had reliable contact with satellites.

The orientation of the units meant that the raw output was in a right-handed aft-port-down coordinate system. This data was converted to a forward-port-up coordinate system (see Figure 9) commonly used in ship seakeeping, when it was read in for processing.

An additional NAV420 unit (serial #05012937) on loan from DRDC to AETE was installed on the helicopter. Its orientation was mounting plate down, connector facing aft towards the tail. This gives a forward-starboard-down coordinate system (see Figure 9) which is commonly used in aeronautics.

Figure 7: Motions sensors in Aft SIS

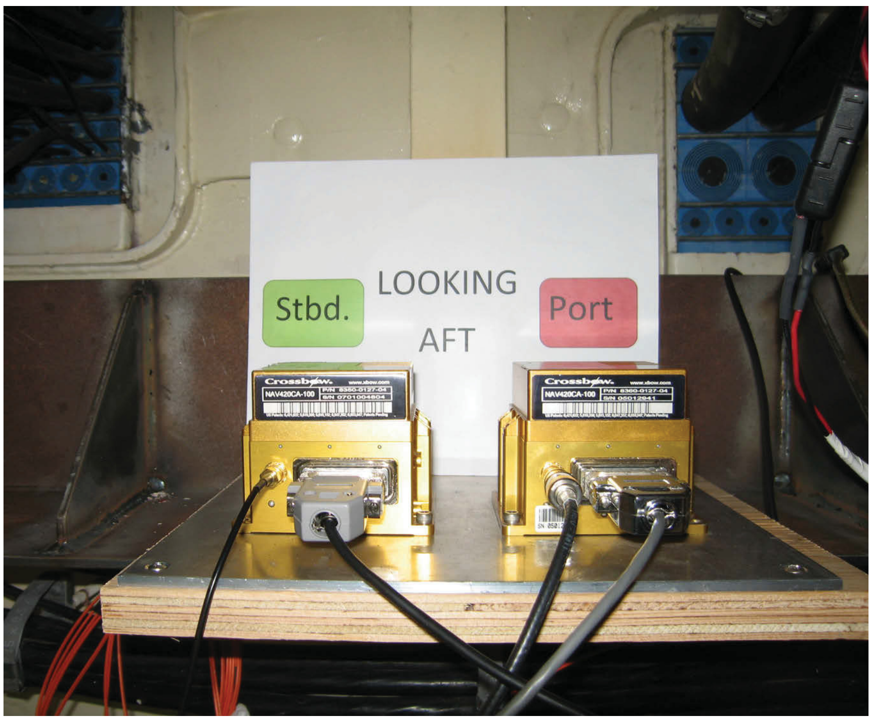

Figure 8: Closer view of motion sensors showing orientation

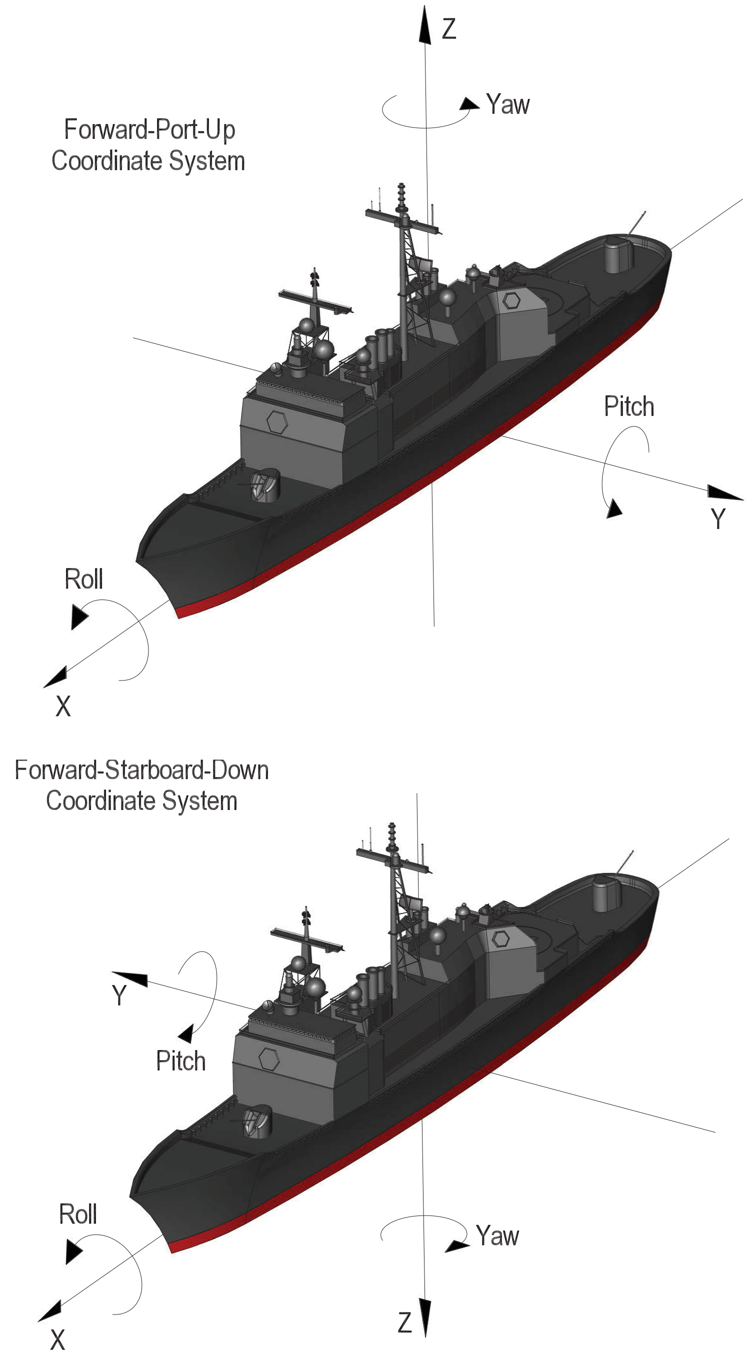

Figure 9: Coordinate systems

2.4 Time synchronization

Conducting a sea trial with multiple data logging computers requires careful attention to time synchronization between the systems. Generally, the internal clocks used in most laptop and desktop computers stray over time (sometimes as much as seconds per day). To correct this, a Network Time Protocol (NTP) time server was installed on two Raspberry-Pi computers[3] (one used as a backup). Time was set to GPS time using an ORCA Model GS-101 clock [6]. This unit was first connected to a GPS antenna at the beginning of the trial and then moved down into the Aft SIS (this unit can maintain millisecond precision for several months). All computers on the DRDC network were then automatically synchronized to the time server. Unless otherwise stated, times referenced in this report are in Coordinated Universal Time (UTC). Local time on the ship was the same as Halifax, Nova Scotia (UTC minus 4 hours).

During the beginning of the trial, there was odd behaviour from the time server. Half of the computers on the network received the correct time while the other half received a time that was 16 seconds ahead. When discovered (at approximately 2013-12-03 12:30:00 [UTC]), that time server was shut down and the backup system was started. No further issues were found with time synchronization from then on. Note that the raw data for the NRC anemometers logged prior to 2013-12-03 12:30:00 [UTC] must have its time corrected by ~15.99 seconds (a jump in the logging time can be seen when the time server was reset).

The AETE video recording computer was not connected to the DRDC network (and its time server). During the first day of the trial, video was timestamped with the local time in Cold Lake, Alberta (UTC minus 7 hours). It was later adjusted to UTC by manually setting the computer clock equal to the DRDC UTC time display located next to the video recording computer in Flyco.

The helicopter DAQ system was timestamped to UTC using a separate independent system.

The IPMS (see Section 2.2) is hypothetically timestamped to UTC but in practice without a proper time server, this time drifts. During the sea trial, IPMS times and corresponding UTC times were recorded periodically (about twice per day). These times were used to re-adjust the IPMS timestamps to UTC. IPMS was approximately 1 hour, 4 minutes ahead of UTC.

2.5 Sea state measurement

Sea state (as defined by Table 3) is an important parameter for SHOL related activities as they affect ship motions. Generally on sea trials when sea state data is needed, a wave buoy would be deployed for direct measurement. However, the launch & recovery of a

[3] The Raspberry Pi is an inexpensive credit-card-sized single-board computer developed in the UK by the Raspberry Pi Foundation.

wave buoy was not practical in conjunction with activities for this trial. Sea states were instead estimated by visual observation (height, and direction) and by ship motions (for wave period). Sea state forecasting data was at times received from www.PassageWeather.com. Some data can also be derived from moored buoys operated by Environment Canada (see Section 4.7).

Table 3: Sea state table for the open North Atlantic (NATO, 1993) [7]

Sea State Number	Significant Wave Height (m)		Sustained Wind Speed (knots)[1]		Percentage Probability of Sea State	Modal Wave Period (s)	
	Range	Mean	Range	Mean		Range[2]	Most Probable[3]
0-1	0 - 0.1	0.05	0 - 6	3	0.70	-	-
2	0.1 - 0.5	0.3	7 - 10	8.5	6.89	3.3 - 12.8	7.5
3	0.5 - 1.25	0.88	11 - 16	13.5	23.70	5.0 - 14.8	7.5
4	1.25 - 2.5	1.88	17 - 21	19	27.80	6.1 - 15.2	8.8
5	2.5 - 4	5	22 - 27	24.5	20.64	8.3 - 15.5	9.7
6	4 - 6	5	28 - 47	37.5	13.15	9.8 - 16.2	12.4
7	6 - 9	7.5	48 - 55	51.5	6.05	11.8 - 18.5	15.0
8	9 - 14	11.5	56 - 63	59.5	1.11	14.2 - 18.6	18.64
>8	>14	>14	>63	>63	0.05	18.0 - 23.7	20.0

[1] Ambient wind sustained at 19.5 m above surface to generate fully developed seas. To convert to another altitude, H_2, apply $V_2 = V_1(H_2/19.5)^{1/7}$.

[2] Minimum is 5th percentile and maximum is 95th percentile for periods given wave height range.

[3] Based on periods associated with central frequencies included in Hindcast Climatology.

2.6 Supplementary anemometers

An important objective of this trial was the validation of wind tunnel experiments conducted by NRC. To this end, three RM Young® Model 81000 ultrasonic anemometers [8] were installed on the ship to supplement the ship's anemometers shown in Figure 10.

Two of the anemometers were fitted to an aluminium pole, shown in Figures 11 & 12, designed to fit the mounts for the ship's flagstaff. They were mounted at 3 m and 5 m above the deck. The third anemometer was mounted in the mast on the ship's centreline, level with and approximately 7 m forward of the ship's anemometers (see Figure 10). Cables from these sensors led back to a weatherproof enclosure (Pelican™ case) located outside in port breezeway (see Figures 13 & 14) which was connected to the DRDC network.

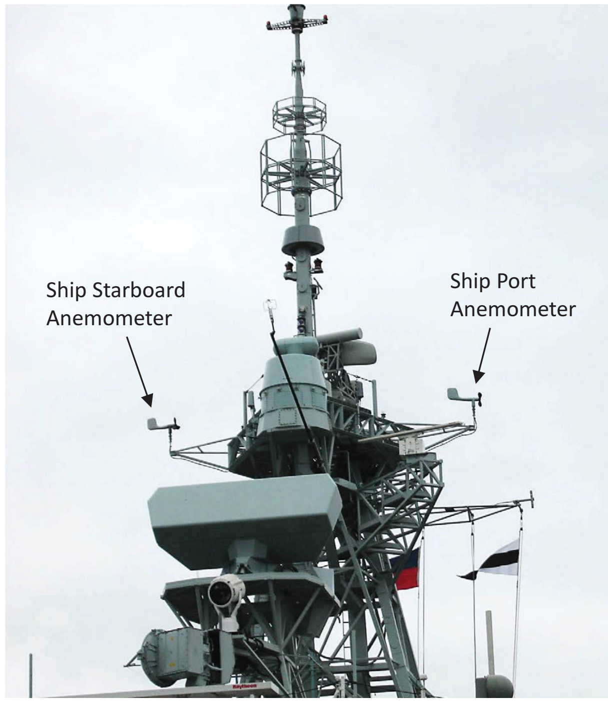

Figure 10: Ship anemometers

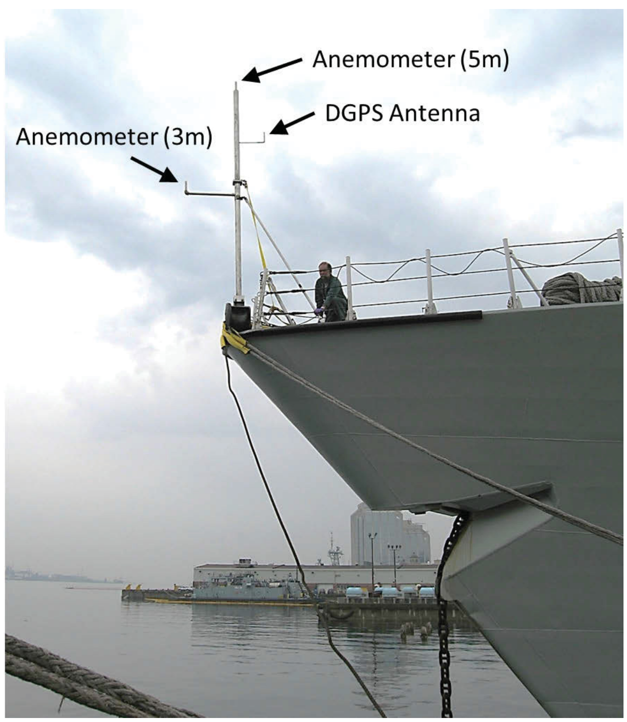

Figure 11: Bow anemometer pole showing sensor mounts

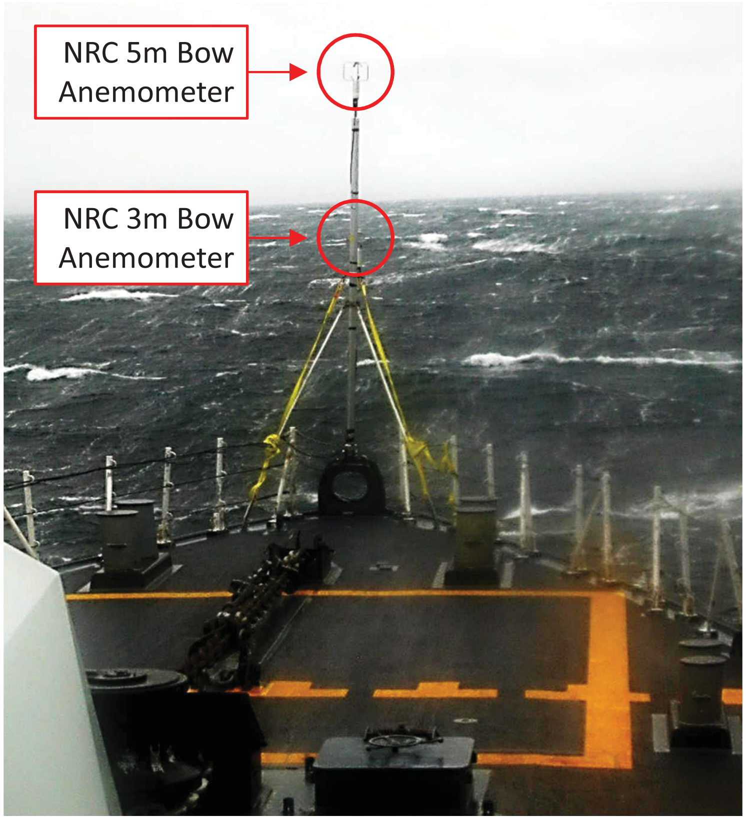

Figure 12: Bow anemometer pole

Figure 13: Pelican case in breezeway

Figure 14: Logging hardware in Pelican case

2.7 Meteorological sensors

Meteorological instruments were installed on the rail of the port bridge wing as shown in Figure 15. These included a HC2-S3-L multi-sensor [9] for air temperature and relative humidity (S/N #0061012374), and a 61302V barometric sensor [10] to measure atmospheric pressure (S/N #H4960027). Cables from these sensors fed to the same Pelican case in the breezeway used by the supplementary anemometers (see Section 2.6).

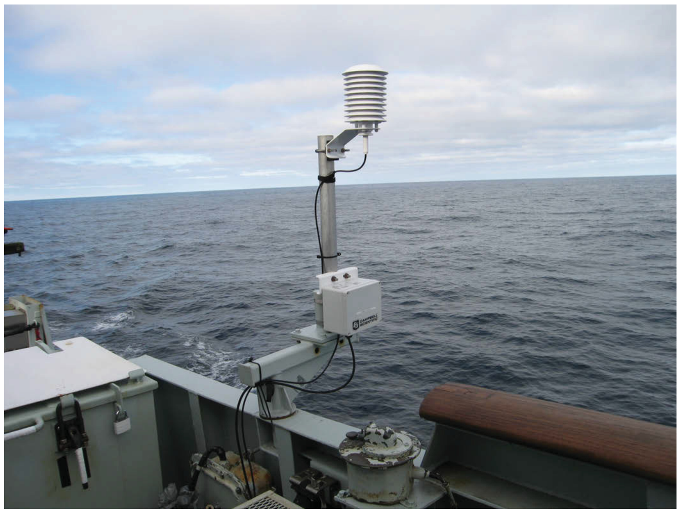

Figure 15: NRC meteorological sensors

2.8 Bow vertical velocity

In the event that the ship might undergo significant pitching motions due to the sea state that might affect the wind measurements at the bow due to large vertical motions, an accelerometer was mounted to the base of the bow anemometer pole. The sensor, an IC Sensors model 3145 signal conditioned accelerometer (20 g range, S/N #9720-014-0338) [11], was oriented vertically and logged by the same data acquisition system used to acquire the meteorological data (see Section 2.7).

2.9 Video

Helicopter operations were recorded with a set of high definition video cameras installed by FMF Cape Scott for AETE. Two fixed-view cameras were located on the starboard side of the flight deck (Figure 16), and one pan & tilt camera was installed on the hanger face just below the horizon bar as shown in Figure 17.

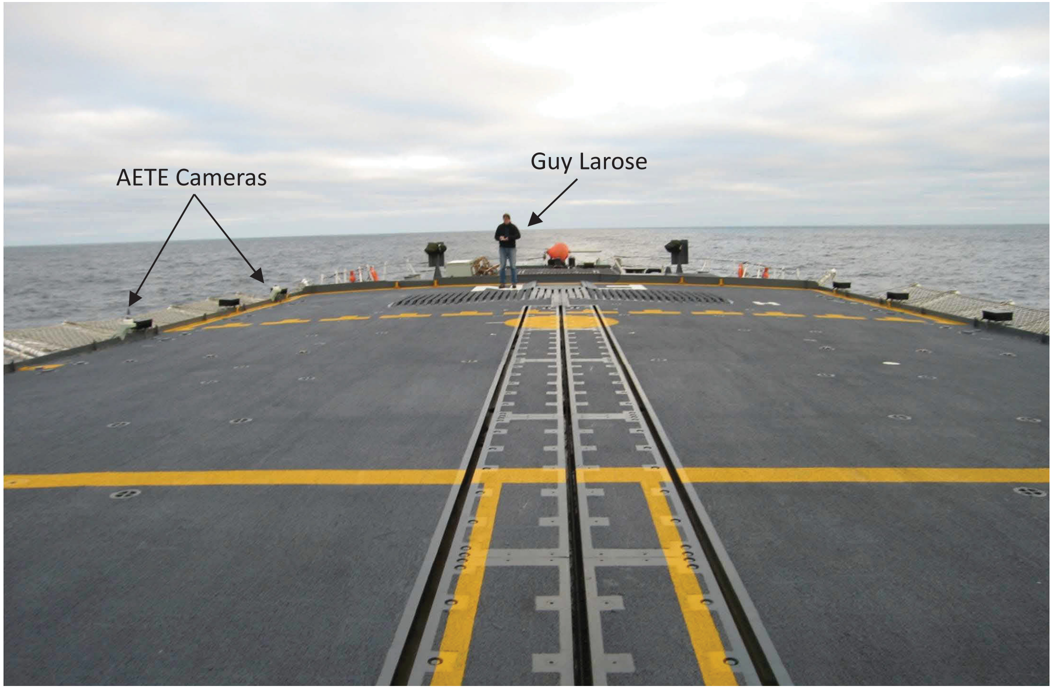

Figure 16: Flight deck

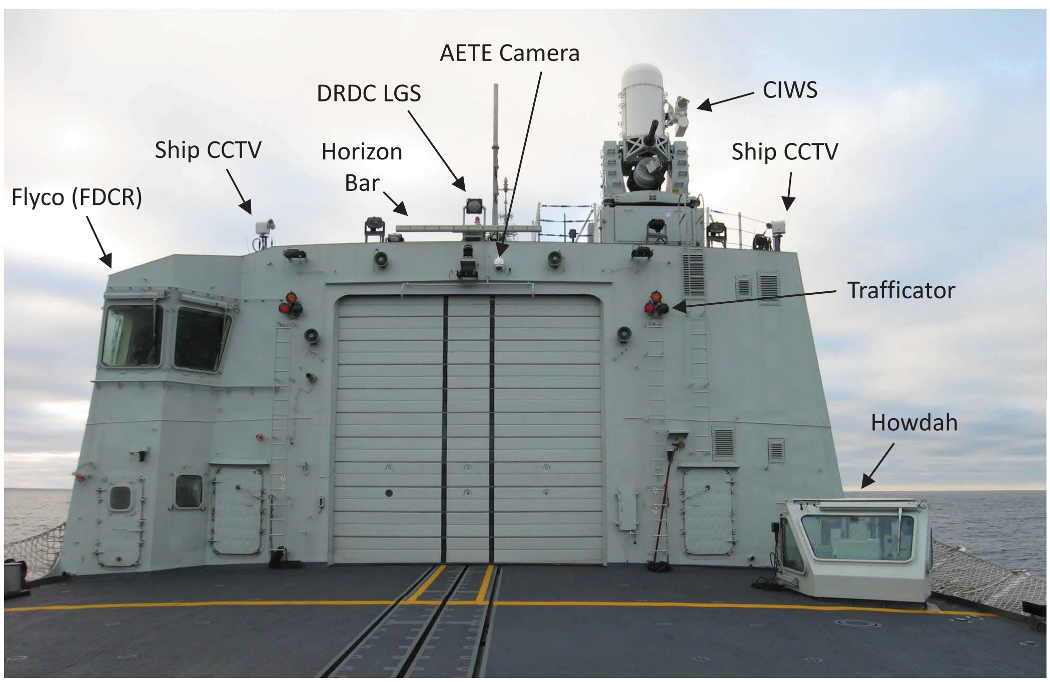

Figure 17: Hanger face

2.10 DRDC network

This section briefly describes the configuration of the DRDC computer network used for the FDMS, BMIS, and other data acquisition used on the sea trial.

Network computers acquired data continuously and displayed various data to monitors located in Aft SIS, Flyco, howdah (a.k.a. LSO compartment), ADR, and on the hangar face.

A key feature of the DRDC network was its connection to the NDDS through a data diode sub-assembly depicted in Figure 18. This assembly was designed to prevent any fortuitous conductor connection with the use of optical isolation techniques. It also prevents any transmission to the NDDS network by forcing all communications through a null (one-way) serial interface connected to the virtual NDDS ports.

In the preliminary plans for this configuration, two identical NDDS logging systems were to be used for separately logging ports 14041 and 14001. This was reduced to a single system (logging both ports simultaneously) for the actual trial.

The following paragraphs reference the computer numbering scheme used in Figure 18 and Figure 19.

The virtual NDDS port logging laptop-1 was connected to the NDDS LAN #2 in the Aft SIS via an optical isolator. The isolator consisted of a copper-to-fibre-to-copper conversion wherein the connection to the ship's NDDS port was made with a shielded RJ45 cable which then connected to fibre-to-optical converter. Optical cable from this converter connected to an optical-to-serial converter, which was connected by a serial cable to laptop-1. Software used by this computer was written using LabVIEW® 2013 DS2. The program waits for ASCII NMEA messages to be received on specific multicast IP addresses and ports (14041 & 14001) from the NDDS network. It then time-stamps and logs specific sentences types (as listed in Section 2.1) and re-transmits them through a null (one way) serial interface to laptop-3. The NDDS logging laptop-1 maintained proper time using a dedicated ORCA CS 101 clock and locally resident time-serving software.

The serial-to-network conversion and multicast laptop-3 logged the serial data received from laptop-1 and re-transmitted the data through a connection to the DRDC network. These laptops used customized LabVIEW code to convert the serial data to an ASCII multicast on the DRDC network.

The Raspberry Pi controller laptop-5 was used to monitor and maintain the Raspberry Pi time servers, the LGS controller, and the three anemometer acquisition computers on the bridge wing.

The NI-DAQ acquisition controller laptop-6 received meteorological data (see Section 2.7) broadcasted by the NI-DAQ system located on the bridge wing. This data was logged lo-

cally and transmitted over the network using the UDP network protocol as ASCII formatted NMEA messages. The computer operating system was Windows 7 with custom-built LabVIEW acquisition software. The computer maintained time synchronization by using Dimension 4 software which received the NTP time signal from the NTP server.

The TOG server (laptop-7) performed calculations necessary for the FDMS main display (see Section 3). It broadcasted data in an XML format over the network using REST web services and the HTTP protocol. The computer operating system was Windows 7 and the server software was developed using C# and the .NET framework version 4.0. Time synchronization was maintained using the NTP time signal processed by Dimension 4 software.

Connection for up to three computers (8, 9, & 10) were available on the network to post-process and analyse data residing within the DRDC network. None of these computers were set-up to auto-synchronize with the NTP time server.

The NAV420 acquisition computers (11 & 12) received vessel motion data from the sensors described in Section 4.3. The NAV420 data was logged locally to file and transmitted over the network using the UDP network protocol. The transmitted data over the network retained its original ASCII NMEA message style. Both computer operating systems were Windows 7 with customized LabVIEW data acquisition code. Time synchronization was maintained using the NTP time signal processed by Dimension 4 software.

Laptop-13 provided the video feed to the FDMS touch screen interface in the LSO compartment (howdah). The computer operating system was Windows 7 with the display code was written using LabVIEW. Time synchronization was maintained using the NTP time signal processed by Dimension 4 software. It received and displayed the following UDP multicast data streams:

a. ASCII NMEA messages containing ship motions as broadcasted by the NAV420 acquisition computers;

b. Tactical operator guidance information as broadcasted using REST HTTP messages sent by the TOG server;

c. ASCII NMEA messages containing anemometer data as broadcasted by the anemometer acquisition computers; and

d. ASCII NMEA messages containing ship heading and speed over ground data as broadcasted by the NDDS acquisition computers.

As shown in Figure 19, Laptop-14 was a duplicate of laptop-13 and fed the FDMS touch screen interface in Flyco. Also in Flyco was laptop-14 with a similar configuration but was set to feed the BMIS (Section 3.1) touch screen interface. The network switch here

had a Raspberry Pi unit used to control the LGS lighting system on the hangar face (see Figure 17). A printer was also installed in Flyco for local use.

Laptop-16 in the ADR was also a duplicate of laptop-13 and used to feed another FDMS touch screen interface in this compartment.

The LSO compartment contained only the FDMS touch screen interface which was being fed by laptop-13 in the Aft SIS. The GPS antennas for the two NAV420 units were attached to the inside of this compartment's aft-facing window.

A pelican case (Figures 13 & 14) located in the port breezeway also contained hardware connected to the DRDC network. This included three Raspberry Pi mini-computers used to acquire data from the three supplementary anemometers (see Section 2.6) and a NI-DAQ system which fed data to laptop-6 for acquisition.

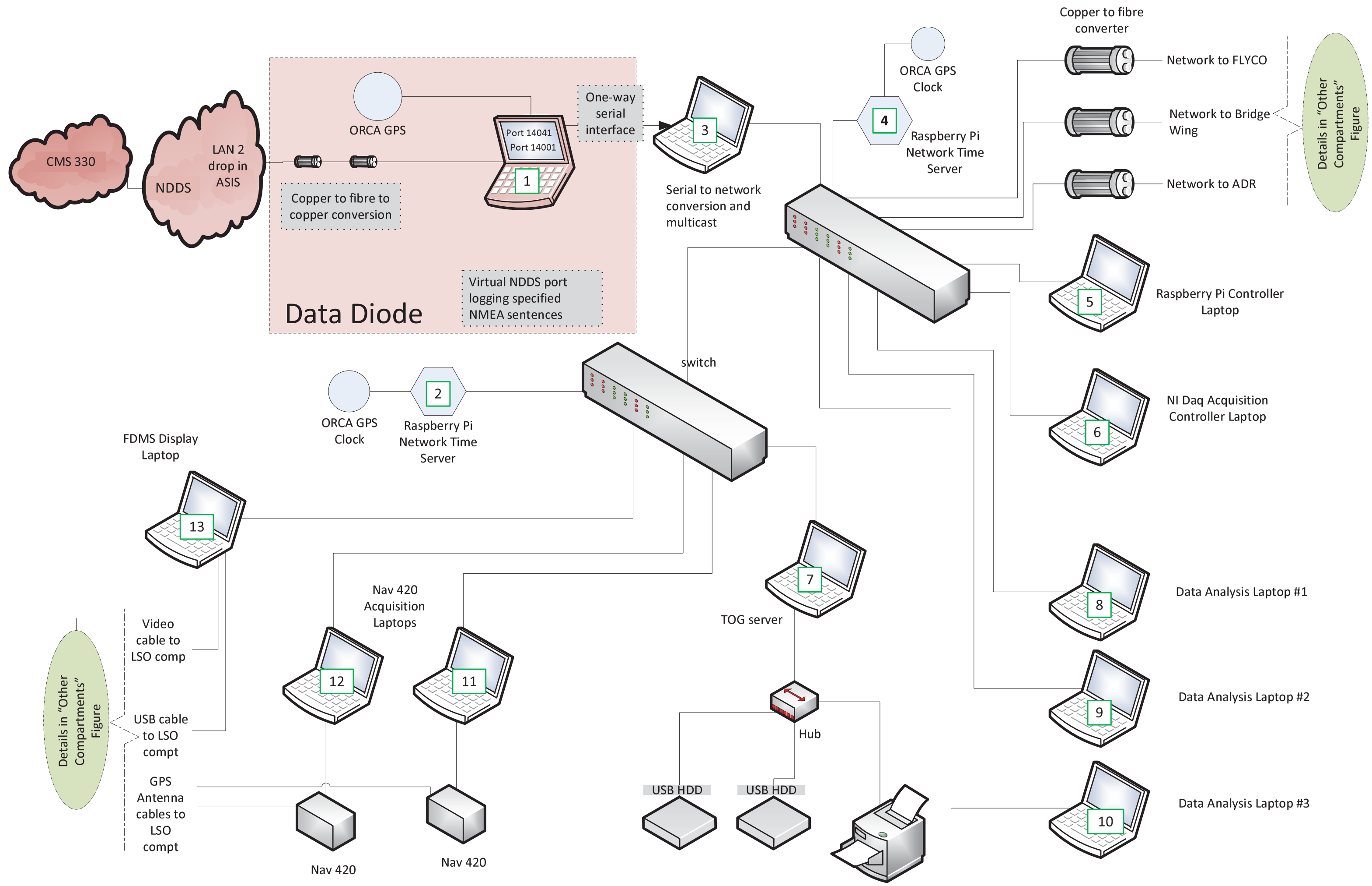

Figure 18: FDMS and data acquisition configuration in Aft SIS

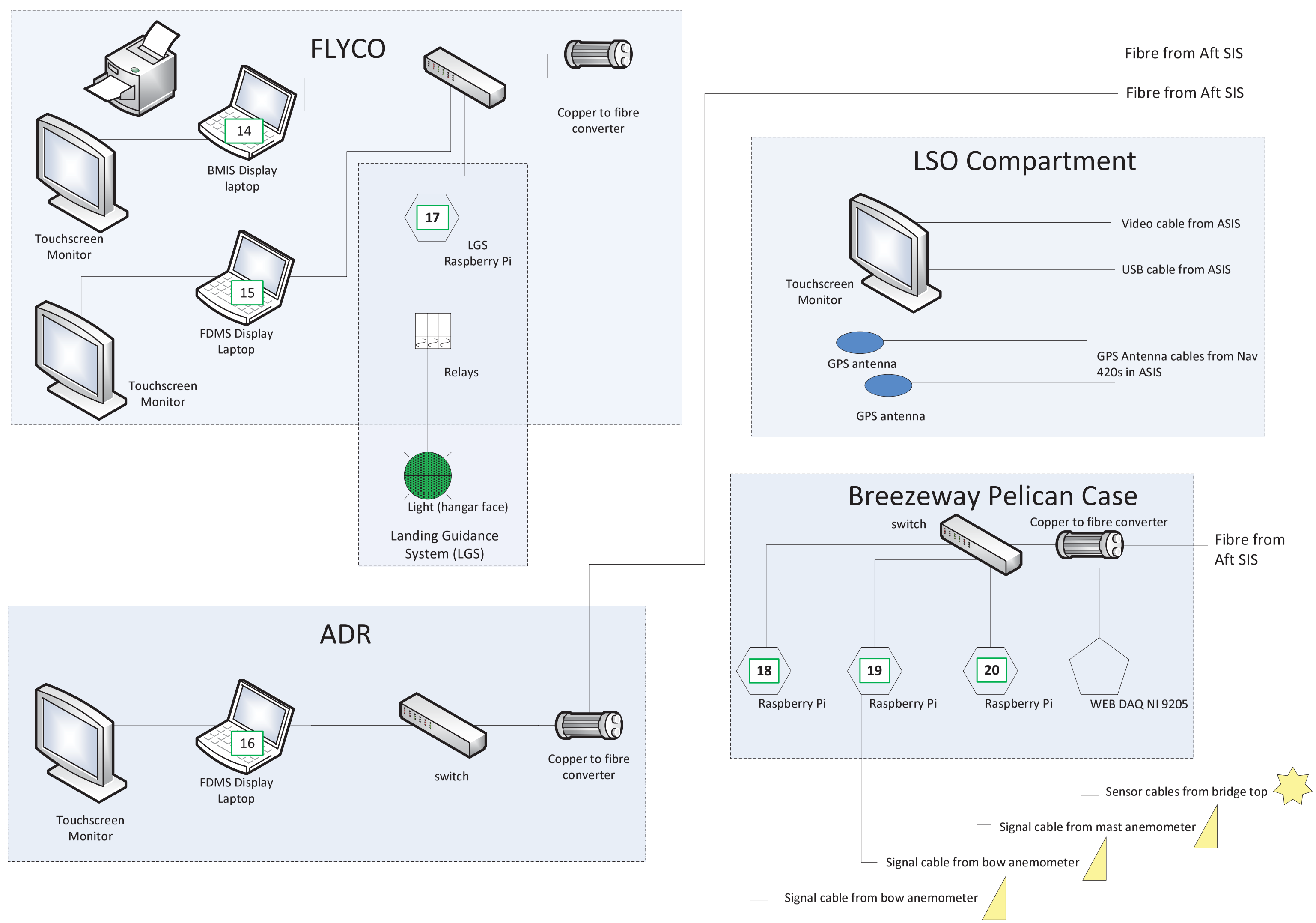

Figure 19: FDMS and data acquisition configuration in other compartments

3 Flight Deck Motion System (FDMS)

In support for SHOL activities, the DRDC prototype Flight Deck Motion System, (FDMS) [12, 13, 14] was installed for the trial. The FDMS creates an integrated display for live streaming of ship and environmental data. Its primary functions are to provide Situation Awareness (SA) in preparing for an operation, and real-time guidance during an operation.

The primary interface of the FDMS is the LSO display (also referred to as the main display). It is composed of three separate operator guidance tools; the ship's Situation Awareness Operator Guidance System (SA-OGS), the Real-Time Flight Deck Operator Guidance System (RTFD-OGS), and the Quiescent Period Indicator (QPI). The ships SA-OGS provides the operator with real time ship logistic information for planning ship operations while the RTFD-OGS and QPI are used during a ship operation (such as landing or launching the helicopter). The LSO display is shown annotated in Figure 20. The SA-OGS and RTFD-OGS are displayed side-by-side with the QPI and set-up panel spanning the top of the screen. The bottom of the screen contains the Mode Selection Panel (MSP) used to select the appropriate mode for the current operation (e.g. night-landing). Each mode of operation has its own specific set of operational limits that are loaded into the display when a mode is selected.

An additional screen designed primarily to visualize recent motion history, can also be used to mark events as a test progresses. This display, shown in Figure 21, produces a strip chart of ship motions for the latest 2 minutes. A button push causes a vertical yellow line to appear in these charts, marking an event. The screen can then be printed for use in post-analysis, but no data is saved to file.

A typical procedure during a DRDC supported SHOL sea trial was to produce motion-estimate plots for the current or expected sea states before a given morning or afternoon flight set. These, along with wind forecasts, are used to determine which points in the test program could be achieved and to determine required ship courses and speeds. These plots were generated using a utility that is part of the TOG server, a component of the FDMS. An example of these plots is shown in Figure 22 (also referred to as 'peanut plots' because of their characteristic shape).

In Figure 22, roll angles were calculated for four ship speeds (0, 10, 20, & 30 knots) for a sea coming from 210° with a significant wave height of 1.5 m and an average period of 8 seconds. Each contour line represents the predicted RMS roll angle (multiplied by a confidence factor[4]) for a given speed at every heading. For example, at 20 knots on a heading of 70°, roll angle is not expected to exceed 8°.

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[4] A confidence factor of 3 is typically used. This means the motions shown on the plot are 3 standard deviations from the mean. This gives a probability of exceedance of ~0.3%.

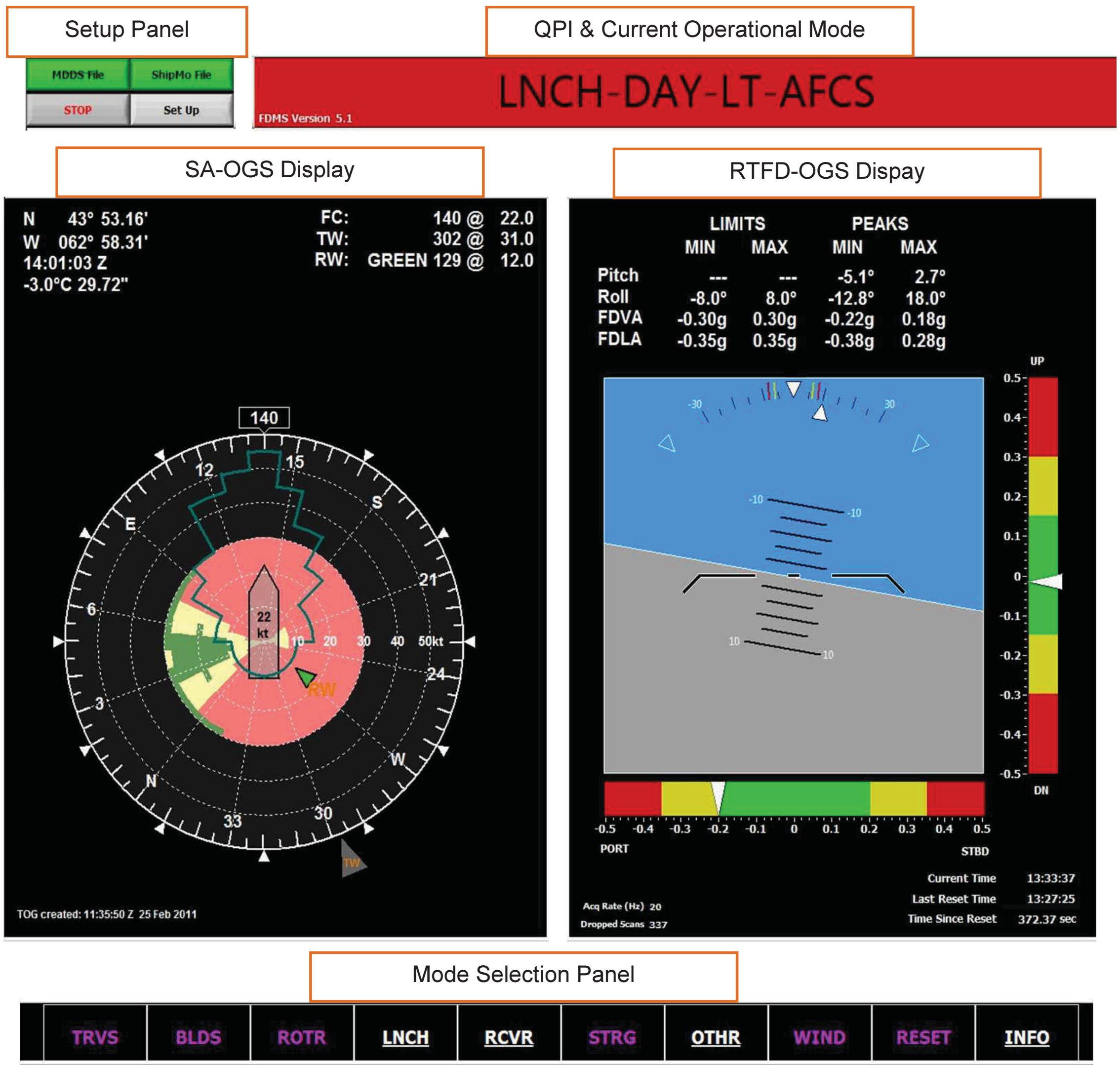

Figure 20: Annotated FDMS main display

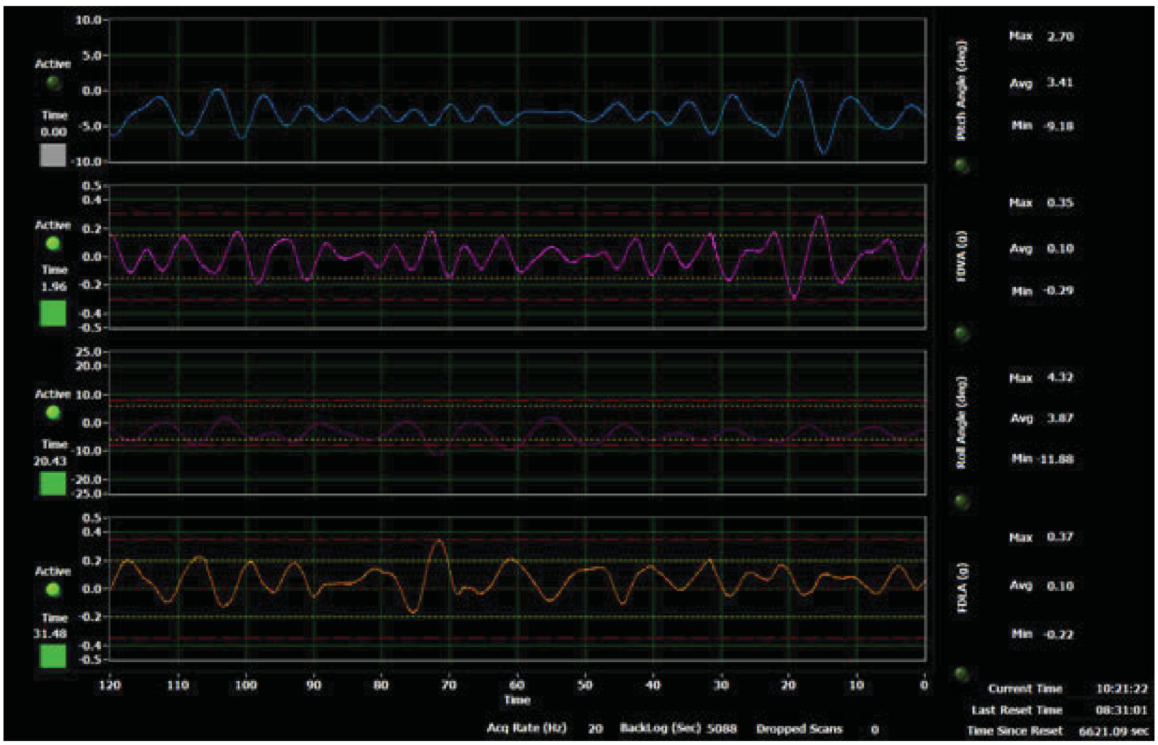

Figure 21: FDMS chart display

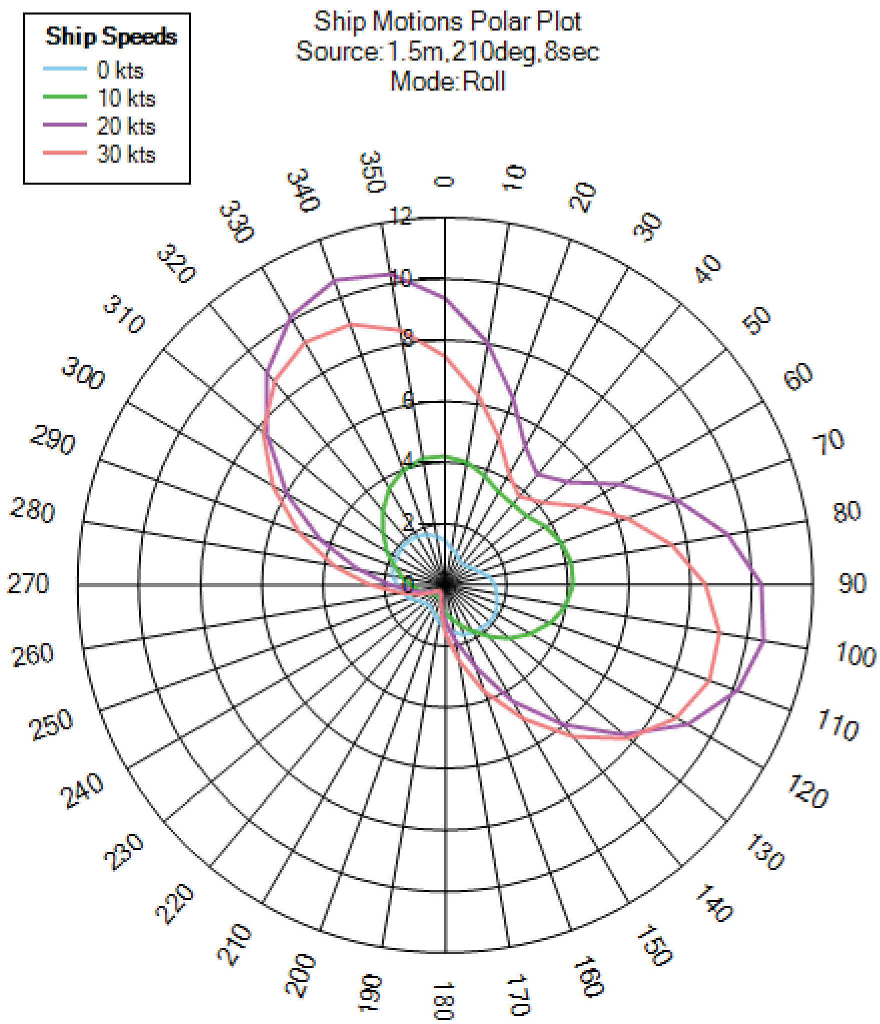

Figure 22: Example motion estimate plot

3.1 BMIS display

In order to support the objective of quantifying potential bias in the ship's anemometers, an additional display was developed for this sea trial. This display, the Bow-Mast Instrumentation System (BMIS), has real-time feeds from both the ship's anemometers and the three supplementary anemometers at the bow and mast. Note that all values in the display are for relative wind[5] as measured, not true wind. Shown in Figure 23, the BMIS display has three main areas; the numeric anemometer readings on the top left, date & temperature on the upper right, and plots on the bottom.

The numeric readings area for the anemometers has two sections; the 'ACTUAL' are the instantaneous feeds, while the 'MEAN' are the average values since the last reset (by pressing the 'RESET' button on the bottom right). The format is defined by:

'Label' 'Direction-Name' Relative-Speed-in-knots @ Relative-Wind-Angle

The labels are defined as follows:

- 'Port' is ship's port anemometer;
- 'Stbd' is ship's starboard anemometer;
- 'Mast' is NRC's anemometer in the mast;
- 'Bow1' is NRC's lower anemometer at the bow (3 m height); and
- 'Bow2' is NRC's upper anemometer at the bow (5 m height).

The direction names depend on the value of the Relative Wind (RW) angle such that:

- 'NOSE' is displayed when $355^\circ <= RW <= 5^\circ$;
- 'GREEN' is displayed when $5^\circ < RW < 175^\circ$;
- 'TAIL' is displayed when $175^\circ <= RW <= 185^\circ$; and
- 'RED' is displayed when $185^\circ < RW < 355^\circ$.

Note that when the direction name is showing 'TAIL' or 'NOSE', the numeric value for the direction angle in degrees is not displayed (as shown in Figure 23 for 'Bow2').

The data on the top right show the current UTC date & time on top and the Outside Air Temperature (OAT) and barometric pressure (in inches of mercury) on the bottom. The

[5] Relative wind direction is defined from 0°to 359°. 0°is wind coming from the bow, 90°is wind coming from the starboard side, 180°is wind coming from the stern, etc.

‘SHIP OAT’ is data from the ship’s sensors via the NDDS and the ‘MAST OAT’ is data from NRC’s sensors (which were actually located on the port bridge rail, see Section 2.7).

The polar plot (which can also be switched to a pie slice section for more focused view) shows the relative wind vectors from all of the sensors (vector display is customizable in that they can be re-labelled, re-coloured, or hidden as needed). The vectors move in real-time as they receive updated data from the DRDC network. The update frequency for all sensors was set to 1 Hz (this was the sampling frequency of the ship’s anemometers). The NRC anemometers were acquired at 30 Hz but were decimated to 1 Hz for broadcast purposes. To keep the animation of the vectors looking smooth, a back-average of 5 samples (5 seconds) was applied.

Directions for the vectors in the polar plot can be set either with respect to the bow (data as measured) or relative to a ‘Truth Anemometer’. In relative mode, the selected ‘Truth Anemometer’ will always appear as coming from 0° with the others showing their directions with respect to this reference.

The strip charts on the right show the time histories of the sensors for the latest 2 minutes (data as broadcast, no back-average applied). This data is always shown relative to a chosen ‘Truth Anemometer’.

The button on the bottom left (labelled ‘MDDS Stream’ in Figure 23) is a user-configurable button used to select from pre-set configurations for the display. The other buttons are self-explanatory.

This display was found to be particularly useful during the trial when NRC was given time to the run the ship at different speeds and headings to systematically investigate readings over a range of relative wind values.

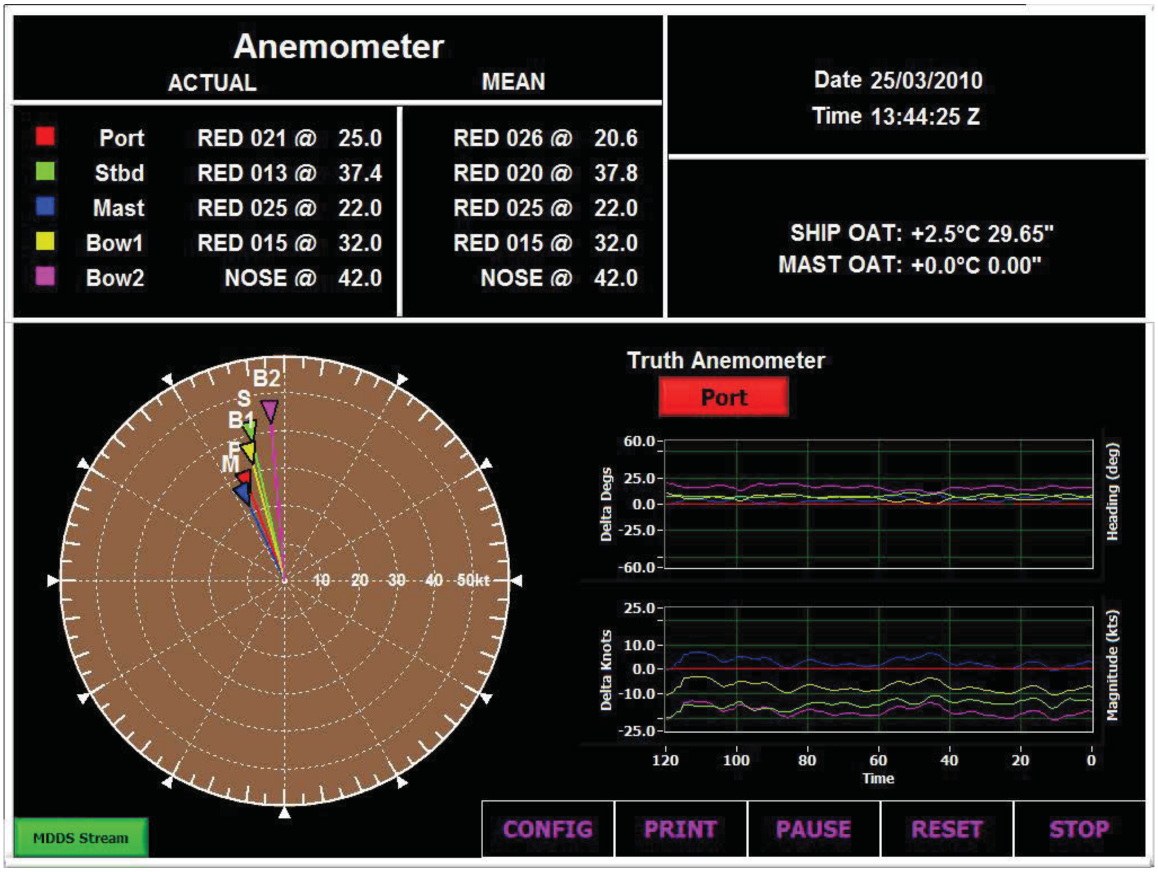

Figure 23: BMIS display

3.2 FDMS and BMIS installation

Most of the FDMS computers were located in Aft SIS as shown in Figure 24. The primary components were:

- NDDS logging computer;
- NAV420 motion sensors and logging computers;
- TOG server;
- Time server;
- Networking components;
- Touch screen displays in the howdah, Flyco, and ADR (previous trials also had a display on the bridge); and
- Controller computers for each display.

The display for the LSO in the howdah is shown in Figure 25 and the displays in Flyco are shown in Figure 26. The 'Anemometer Display' shown in Figure 26 along with the 'Met Data Logger' and 'Anemometer Controller' computers shown in Figure 24, were to aid in the wind validation task with NRC (see Section 3.1) and are not part of the FDMS.

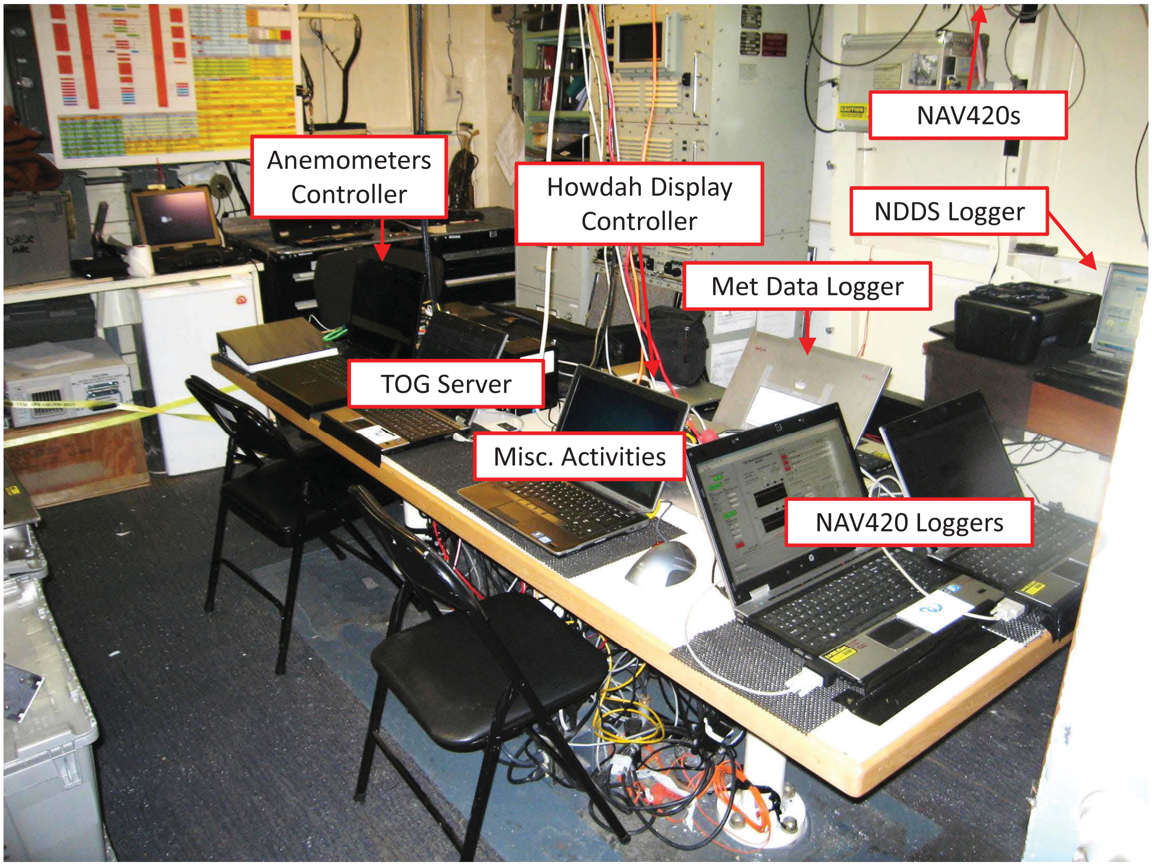

Figure 24: DRDC setup in Aft SIS

Figure 25: DRDC setup in howdah

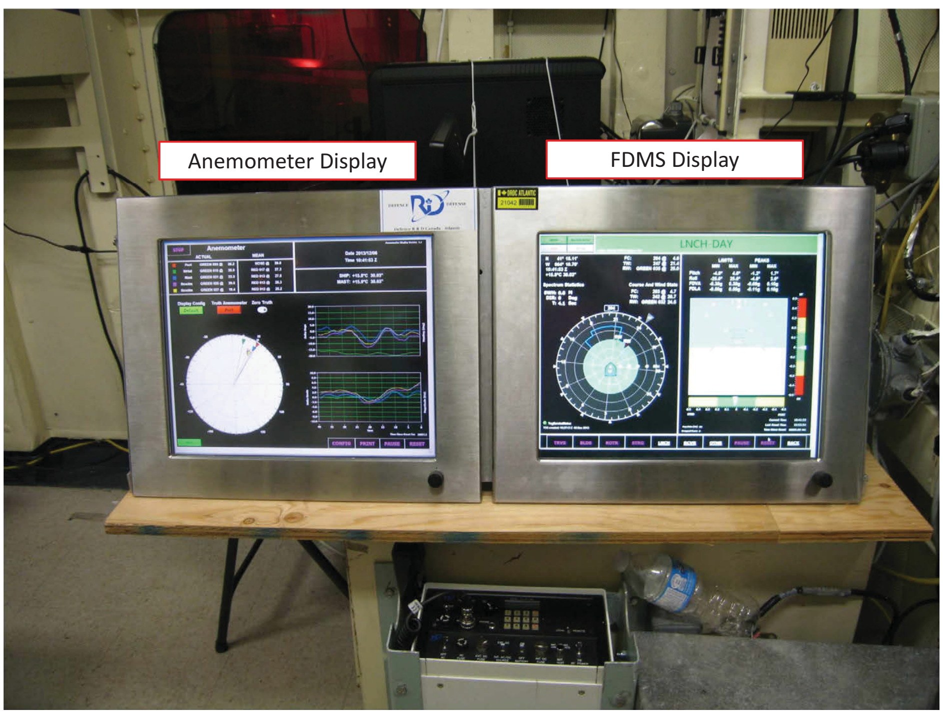

Figure 26: Double display setup in Flyco

4 Trial summary

The trial was conducted from December 2-9, 2013. It involved the ship's crew, an Air Detachment (Air Det) from AETE led by Major Dany Duval, the DRDC team listed in Table 5, and Guy Larose, an aerospace scientist from NRC. A total of six test flights were performed in addition to two separate periods where the ship was dedicated to running patterns specifically for wind data analysis. Flight tests ended late afternoon Friday December 6 (Halifax time) due to an issue with the port landing gear which could not be repaired on ship. A summary of trial activities is given in Table 4 with specific times given in Table 6.

Typically, test flights were performed in the morning (0830 - 1130 Halifax time) and in the afternoon (1300 - 1700 Halifax time). Prior to each flight period, estimates of the expected wind and sea state (with corresponding predicted ship motion envelopes) for that period were made to determine which areas of the AETE test plan could be conducted. At the end of each flight period, relevant data from the ship DAQ system was consolidated and given to the AETE trial team for analysis in conjunction with the acquired helicopter DAQ. Data was also provided to the NRC scientist each evening for analysis and planning purposes.

The ship track for the trial is shown in Figure 27 along with the locations of moored MEDS buoys (see Section 4.7). Trial activities were conducted just outside harbour to as far as ~220 nmi south of Halifax. Weather conditions were generally mild throughout the trial period, briefly peaking at SS-3, but were mostly SS-2 or less with wind in the 15-20 knots range.

Data was collected continuously until the afternoon of December 7, 2013 (Halifax time). The available data coverage for the various data sets is illustrated in Figure 28. Missing data are shown as gaps in the figure and are listed in more detail for each data set in Annex A.

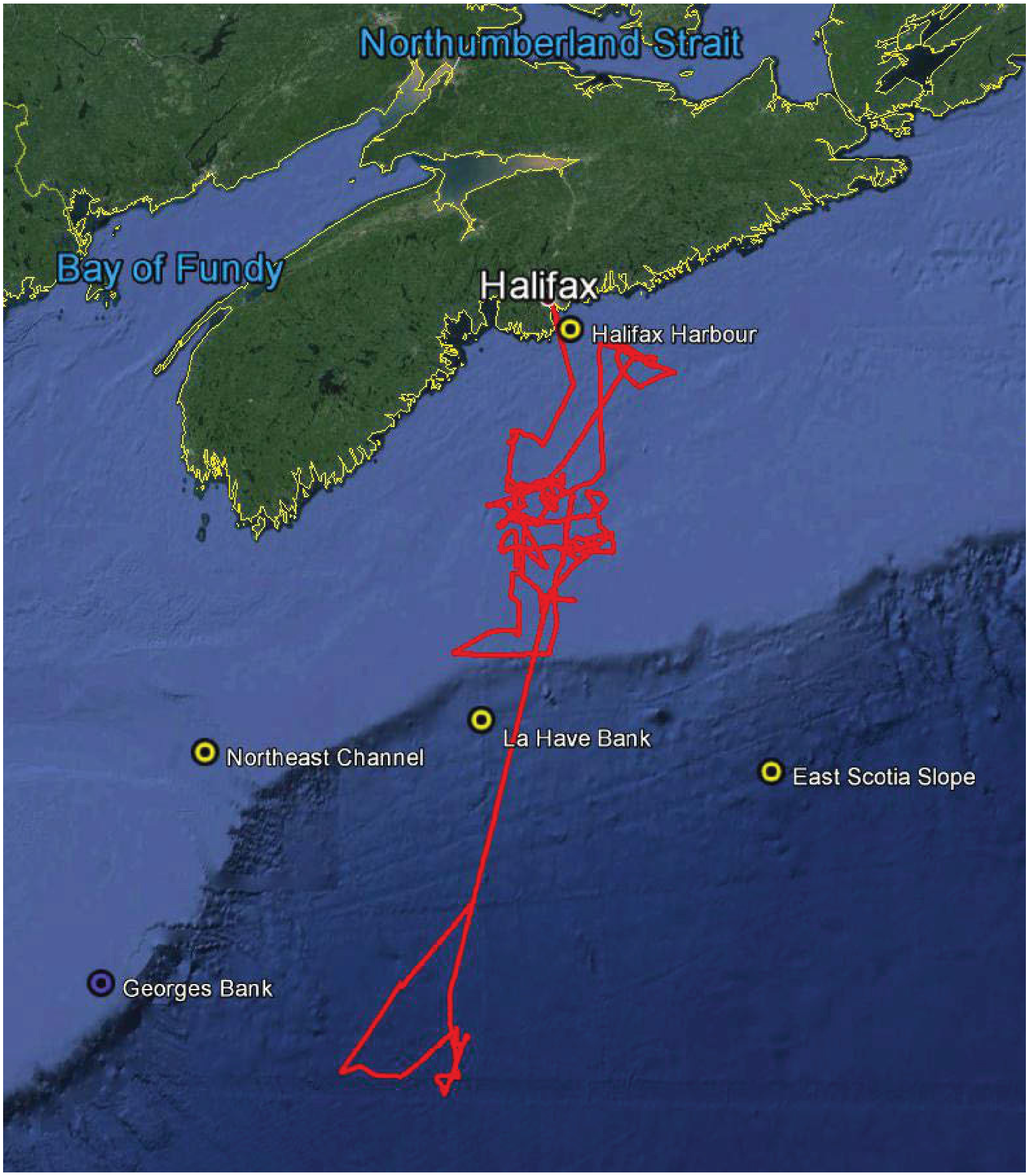

Figure 27: Ship track and MEDS buoys

Table 4: Trial activities summary

Date & Time (Local*)	Activities
April 2013 - November 2013	Planning and preparation.
Monday 9-Nov-2013 to Friday 13-Nov-2013	FMF Cape Scott executes ECs such as mounts and wiring for trial instrumentation.
Monday 18-Nov-2013 to Thursday 21-Nov-2013	DRDC trials team does preliminary fit-out of equipment on ship for tests and shake-downs. COMSEC inspection of kit is performed. Kit is removed from ship after testing.
Thursday 28-Nov-2013 to Friday 29-Nov-2013	After a schedule change due to weather, DRDC trials team fits out ship for trial. Logging equipment is turned on a left running.
Sunday 01-Dec-2013	Ship goes to sea to perform a PDE power trial.
Monday 02-Dec-2013	
0930	Ship returns from PDE trial to re-fuel.
1000 - 1300	DRDC trial team embarks at 10am, checks system, sets up remaining equipment (such as the bow pole), and finalizes set-up for trial.
1300 - 1500	Ship sails out past Chebucto Head to receive helicopter from Sheerwater. Wind and sea conditions considered unsuitable for first landing so ship sailed closer to land for more favourable conditions. Helicopter landed ~1500. Ship then proceeded to sea. No other SHOL activities for the day.
Tuesday 03-Dec-2013	
0900 - 1100	An attempt was made to start flight operations but were cancelled due to fog and limited visibility. Instead deck work (blade spread/fold, etc.) was performed.
1300 - 1700	Planned flights were cancelled due to continued fog and poor visibility. No other SHOL activities for the day
Wednesday 04-Dec-2013	
0830 - 1130	Moved to about 25 nmi off Chebucto Head. Visibility was good. Sea State at ~3 m with high winds. Helicopter operations started ~08:30. At ~11:30 one of the tires was pulled off its rim slightly, ending the morning flights.
1300 - 1700	Wheel was fixed over lunch time. Flight operations continued in afternoon.
Thursday 05-Dec-2013	
0830 - 1130	Flight operations were performed. Seas and wind had calmed down considerably.
1300 - 1700	Cancelled afternoon flight program because conditions too mild to perform required test points.

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1800 - 2000	Ship ran patterns to gather data for NRC wind & airwake analysis.
Friday 06-Dec-2013	
0830 - 1130	Moved to ~150 nmi south of the southern edge of Nova Scotia. Conditions warm with improved, but still mild wind speeds. Flight operations were performed.
1330 - 1700	Wind at 20-25 knots. Require 55 knots on the nose for certain test points. Used ship full ship speed to achieve required relative wind. Late in the afternoon, an issue was discovered with the starboard landing gear that could not be repaired on ship. No more test flights could be conducted.
Saturday 07-Dec-2013	
0830 - 1200	Flight operations cancelled due to landing gear, so morning was spent conducted ship patterns for NRC wind validation. Winds were light, sea state 1-2.
1330 - 1700	At ship's request, all trial kit that could be removed and packed up at sea was placed in a store room off the flight deck. No more data acquisition past ~16:30 07-Dec-2013 [UTC].
Sunday 08-Dec-2013	
0830 - 1600	During transit, day was spent cleaning and packing remaining loose gear as well as consolidating & distributing the data sets from DRDC, AETE, and the ship. Wind ~15-20 knots with sea state 1-2.
1600	Ship anchored outside Halifax harbour.
Monday 09-Dec-2013	
0700	Helicopter and some Air Det members disembark ship to Sheerwater.
0830 - 0900	Ship comes alongside at Halifax dockyard.
0900 - 1000	Trial team, remaining Air Det, and related equipment disembark.

*UTC is 4 hours ahead of Halifax local time.

Table 5: DRDC trial team

Name	Position	Location
Eric Thornhill	Defence Scientist	DRDC Atlantic
Roger Arsenault	Engineering Technologist	DRDC Atlantic
Alex Ritchie	Engineering Technologist	DRDC Atlantic
Jim van Spengen	Computer Scientist	DRDC Atlantic

Table 6: Activities times

SHOL Flights	
Times [UTC]	Duration
02-Dec-2013 19:00:00 to 02-Dec-2013 19:56:27	0.94 hours
03-Dec-2013 13:26:00 to 03-Dec-2013 14:45:00	1.32 hours
04-Dec-2013 12:42:34 to 04-Dec-2013 15:37:54	2.92 hours
04-Dec-2013 18:50:51 to 04-Dec-2013 21:03:54	2.22 hours
05-Dec-2013 12:46:19 to 05-Dec-2013 15:12:00	2.43 hours
06-Dec-2013 12:49:54 to 06-Dec-2013 15:20:28	2.51 hours
06-Dec-2013 17:48:00 to 06-Dec-2013 19:34:00	1.77 hours
Total	14.10 hours

Wind Patterns	
Times [UTC]	Duration
05-Dec-2013 22:00:00 to 05-Dec-2013 23:59:59	2.00 hours
07-Dec-2013 12:00:00 to 07-Dec-2013 16:00:00	4.00 hours
Total	6.00 hours

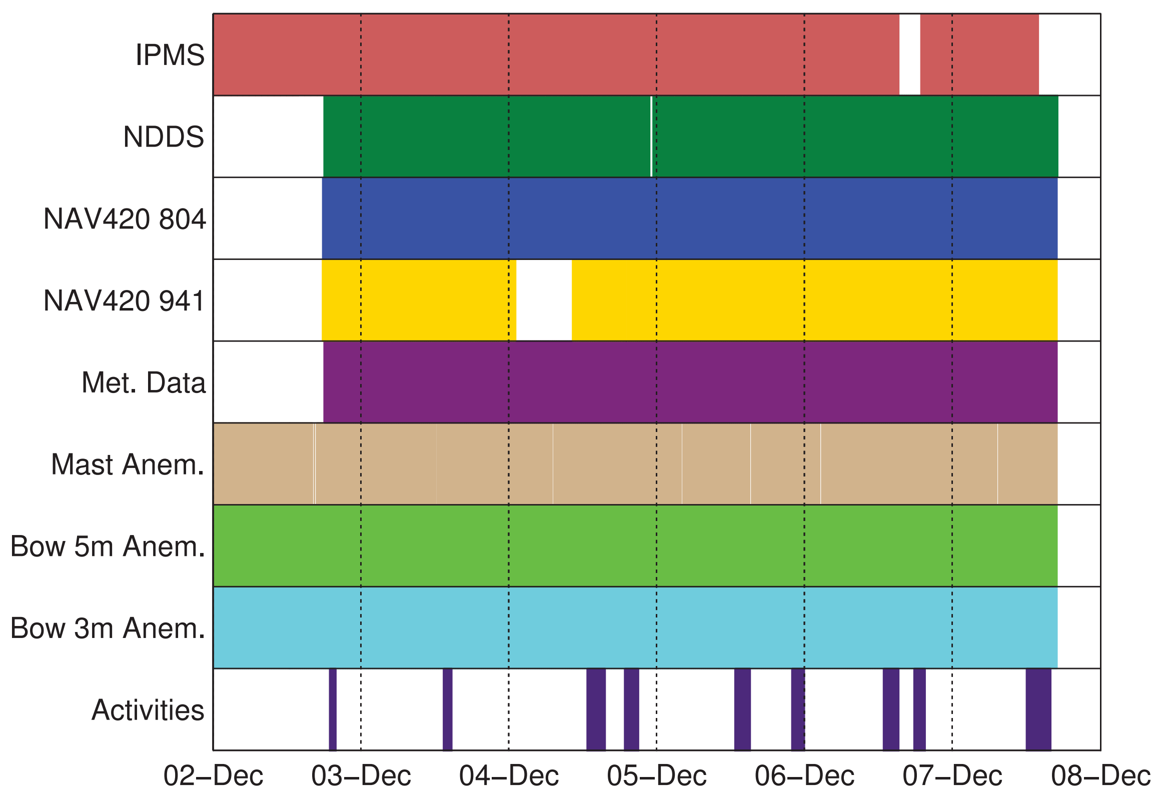

Figure 28: Data coverage

4.1 FDMS activities

Most recently used on the SHOL trials for the CH148 Cyclone on HMCS MONTREAL in 2012, the FDMS is now considered an essential tool for SHOL development activities. The system was used extensively and reliably for all flight operations and wind validation activities on this trial.

An added feature in the current system, over previously used versions, was the addition of logging for TOG updates. Whenever a new sea state and associated TOG data was submitted to the system, this information (along with other configuration settings) was timestamped and logged to file. Some of the results of this log are shown in Section 4.7. In future, this logging capability should be extended to include all FDMS button presses, so that it may be possible to replay the events of an entire operation including which mode and which display were being shown at any given time.

One minor concern, discovered early in the trial was that the ship's anemometers were being shown with the wrong labels; the port anemometer was displayed as starboard, and vice versa. This was a remnant from the 2012 trial on MONTREAL which had its internal NMEA messages incorrectly labelled for these sensors. At the time, the FDMS code was written to read these messages, then reverse the labels to correct for this error. This change in the code was forgotten until it was noticed on the current trial. The code was corrected and recompiled on ship without issue.

A potential problem, noticed during some sharp manoeuvres, was that the motions displayed on the screen from the NAV420 did not seem to match what was being felt. This appears to be related to the sensor and not the display and is discussed further in Section 4.3.1.

Observation of the activities in Flyco during the flight operations suggested that an improvement could be made to the system for future SHOL trials. Throughout a given SHOL flight, the test director in Flyco was using the chart display (discussed in Section 3) to supplement the logging of activities. He would frequently press the event button and then immediately print the chart screen while handwriting a small note about what the event was in a trial log. Afterwards, he would reconcile the printed sheets with marked events and his own short notes to generate a proper log for the operation. This involved significant workload both during and after the flight tests.

It is possible that an "Event Logger" screen could be specifically developed to help the logging process during SHOL activities. The screen could have customizable buttons for marking specific events and all events would be timestamped and logged to file. This logger could be set-up on a separate monitor located beside the main FDMS display monitor (similar to that shown in Figure 23). It is likely that this feature could be developed in time for future SHOL sea trials for the CH148 Cyclone expected to occur in late 2014.

4.2 GLM data

GLM reports [15], which detail the ship's weight, drafts, and hydrostatic stability, were generated each day by ship staff. Copies of these reports were given to the DRDC trial team at the end of the trial. Selected GLM data is summarized in Tables 7 & 8.

Table 7: Drafts and heel

Date [UTC]	AP Draft [m]	Midship Draft [m]	FP Draft [m]	Heel [deg]
2013-12-02	4.984	5.108	5.232	1.08p
2013-12-03	5.031	5.132	5.234	0.44p
2013-12-04	4.979	5.108	5.237	0.47p
2013-12-05	4.943	5.097	5.251	0.97p
2013-12-06	4.929	5.088	5.247	0.44p
2013-12-07	4.886	5.083	5.279	1.63p

'p' indicates to port of midships.

Table 8: Weights and centres of gravity

Date [UTC]	Weight [MT]	LCG [m]	TCG [m]	VCG [m]	GML [m]	GMT [m]
2013-12-02	4903.48	3.556a	0.018p	6.527	284.56	0.9191
2013-12-03	4935.12	3.486a	0.007p	6.512	283.60	0.881
2013-12-04	4904.65	3.579a	0.007p	6.542	284.49	0.854
2013-12-05	4892.83	3.685a	0.016p	6.554	284.58	0.836
2013-12-06	4881.46	3.697a	0.006p	6.559	285.10	0.759
2013-12-07	4880.61	3.867a	0.026p	6.599	284.53	0.768

LCG is relative to midships.
'a' indicates aft of midships, 'f' indicates forward of midships.
AP = 62.25a and FP = 62.25f.

4.3 Ship motions

Ship motions were measured by two NAV420 units (see Section 4.3) located in Aft SIS. Both units logged continuously, but there was a multi-hour gap in the data on 04-Dec-2013, as shown in Figure 28, from the unit with the serial number ending in 941. This was due to the serial-to-USB adapter being accidentally knocked loose on the laptop. For future trials, other laptop/cabling/adaptor connection options will be investigated to find a more robust solution. Data shown here is therefore from the unit with the serial number ending in 804.

A complete history of the measured body frame vertical & lateral accelerations is shown in Figure 29. It was generated by successively plotting the data in each 20 minute data file

saved during the trial. The colours in the plot differentiate the data from the individual files. Also shown in the figure are times when test flights or wind patterns were performed (as listed in Table 6). The sensor locations in Aft SIS was considered close enough to the DLA on the flight deck that acceleration data was used directly for the FDMS without any position correction.

The complete trial roll and pitch angle histories are shown in Figures 30 & 31. In each figure, the angles measured by the NAV420 (sampled at 20 Hz) are shown on the top and those measured by the Ship Inertial Navigation System (SINS) (sampled at 1 Hz, see Section 2.1) are shown on the bottom[6]. Roll angles matched well between the NAV420 and SINS. Pitch angles, however, shown some extreme events in the NAV420 plot that are not seen in the SINS data. These are discussed further in Section 4.3.1.

[6]The SINS defined positive roll angle as starboard up/port down. This was changed to positive port up/starboard down in the figure to match coordinate convention used for the trial data.

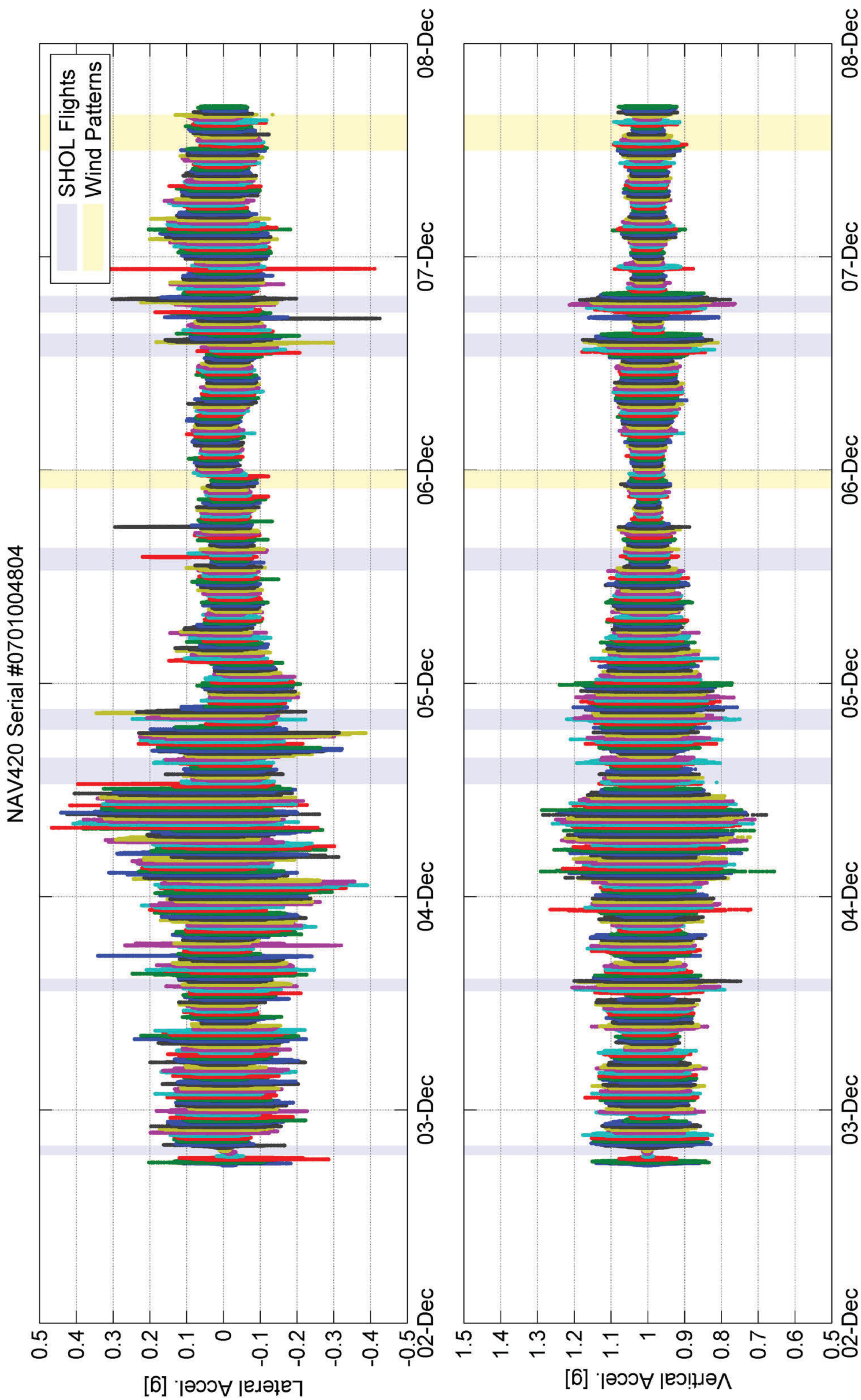

Figure 29: Lateral and vertical flight deck accelerations

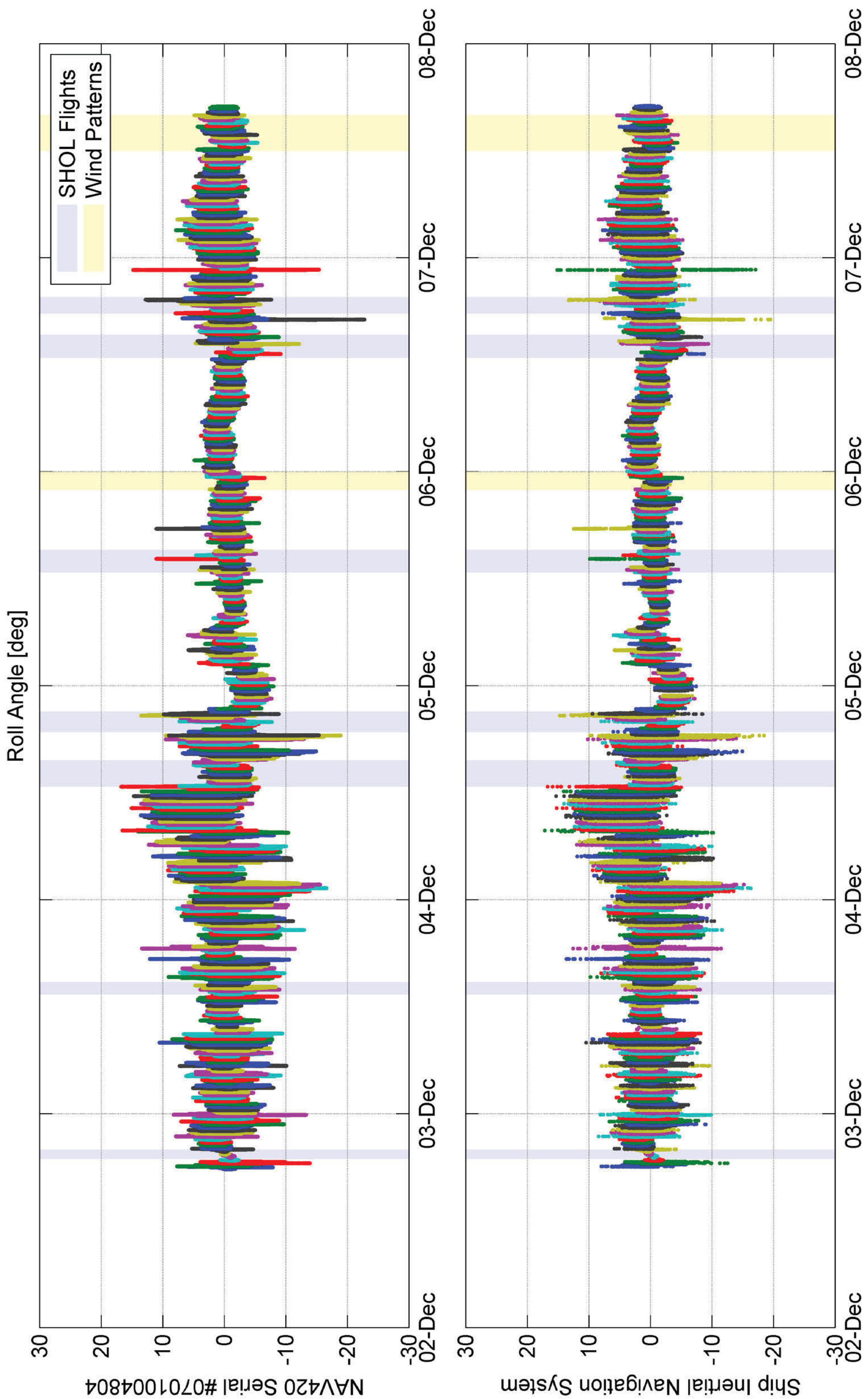

Figure 30: Ship roll angle

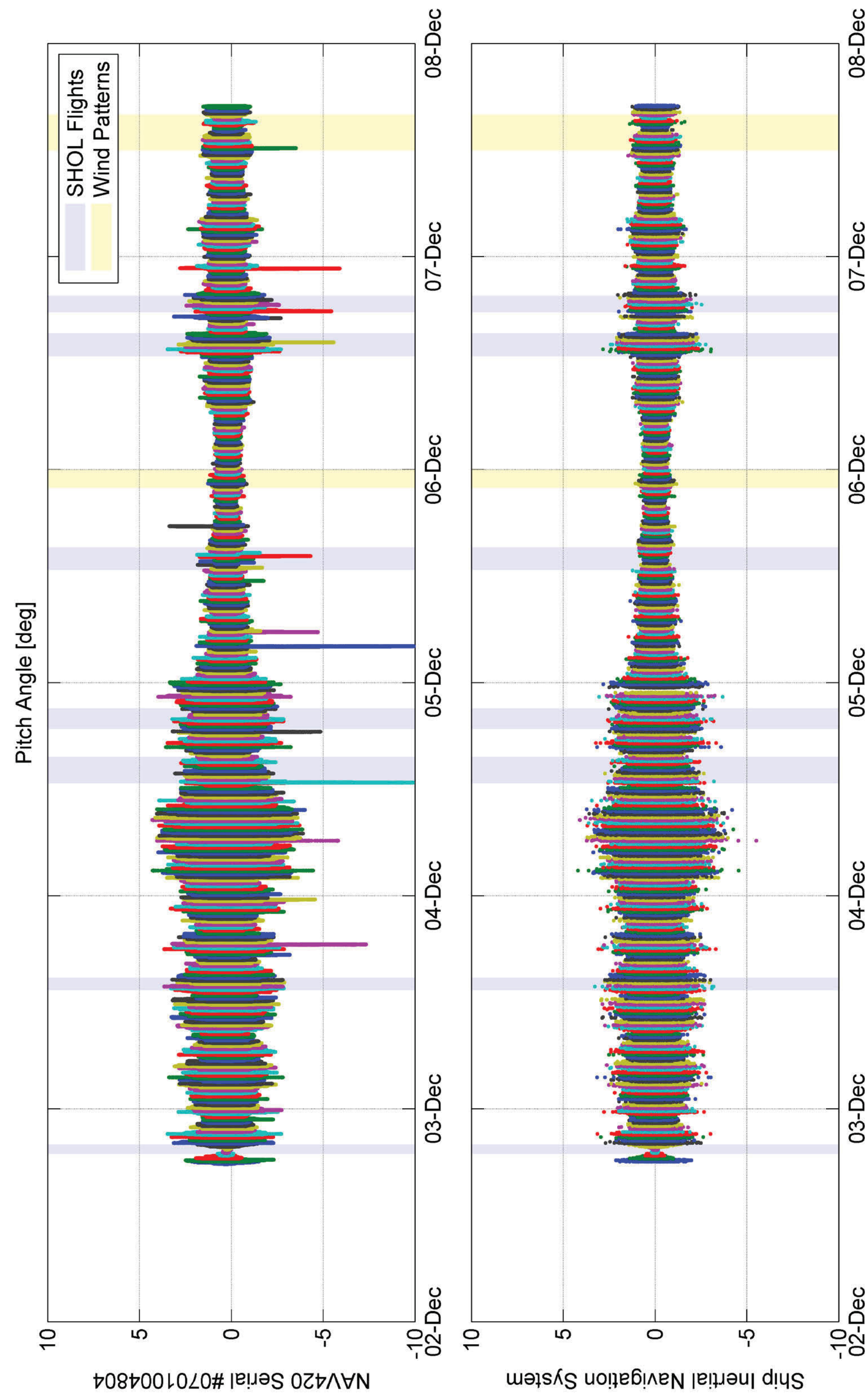

Figure 31: Ship pitch angle

4.3.1 NAV420 errors

Figure 33 shows the ship motions[7] as measured by the NAV420 and by the SINS around a pitch spike reading from the NAV420 at approximately 2013-12-05 04:08 UTC. Prior to 04:02 the pitch and roll were in reasonably good agreement between the NAV420 and the SINS. They then diverge with the NAV420 showing large pitch and roll angles relative to the SINS. The NAV420 pitch reaches ~9° before the signal returns to agreement with the SINS at 04:10. The ship did not pitch 9°, therefore the NAV420 was in error for this period. This seems to have occurred due to a series of sharp turns which began at 03:50. These are shown in the time histories of heading and rate-of-turn as well as in the plot of the ship track shown in Figure 32.

The heading data in Figure 33 shows the NAV420 and SINS data diverging at the beginning of hard 180° turn (03:50). The rate-of-turn data show the SINS data maintaining a constant value for several minutes, consistent with the track data, while the NAV420 reads the initial rate-of-turn value which then increases for the rest of the turn (till ~03:55). The same happens for each manoeuvre in the plot; initial rate of turn is measured correctly, but does not maintain a constant value. By the end of the period shown, the difference in heading between the NAV420 and the SINS is nearly 150°.

Several other examples of the NAV420 misreading pitch and roll relative to the SINS were seen throughout the trial data set. In all cases the discrepancies were initiated by a sharp turn by the ship. One possible explanation for this behaviour is that the NAV420 unit may not have had an adequate GPS connection, which helps it determine heading in its internal Kalman filtering [5]. In previous SHOL trials, the GPS antenna was attached to the roof window of the howdah which gave it a large unobstructed view of the sky. During this trial, it was attached to the howdah's aft-facing window (Figure 17) due to a metal plate covering the top window. The antenna therefore had a restricted view of the sky which may, at times, have resulted in a compromised data feed to the NAV420. Without a GPS feed, the NAV420 depends on its magnetometers to determine heading relative to magnetic north. However, measurement of the Earth's magnetic field inside the Aft SIS was likely unreliable due to the steel structure of the ship and its numerous high voltage electrical cables and equipment. On future SHOL trials, efforts should be made to ensure a reliable GPS feed to the NAV420s.

Until the cause and solution to this issue is determined, SHOL trials relying on the FDMS should attempt to mitigate these misreadings by either monitoring differences in NAV420 roll and pitch with the SINS and alerting the user when they become too large, or by giving a warning during sharp turns that data may not be reliable for several minutes.

[7] Data in Figure 33 was re-sampled to 20 Hz and low pass filtered at 0.1 Hz.

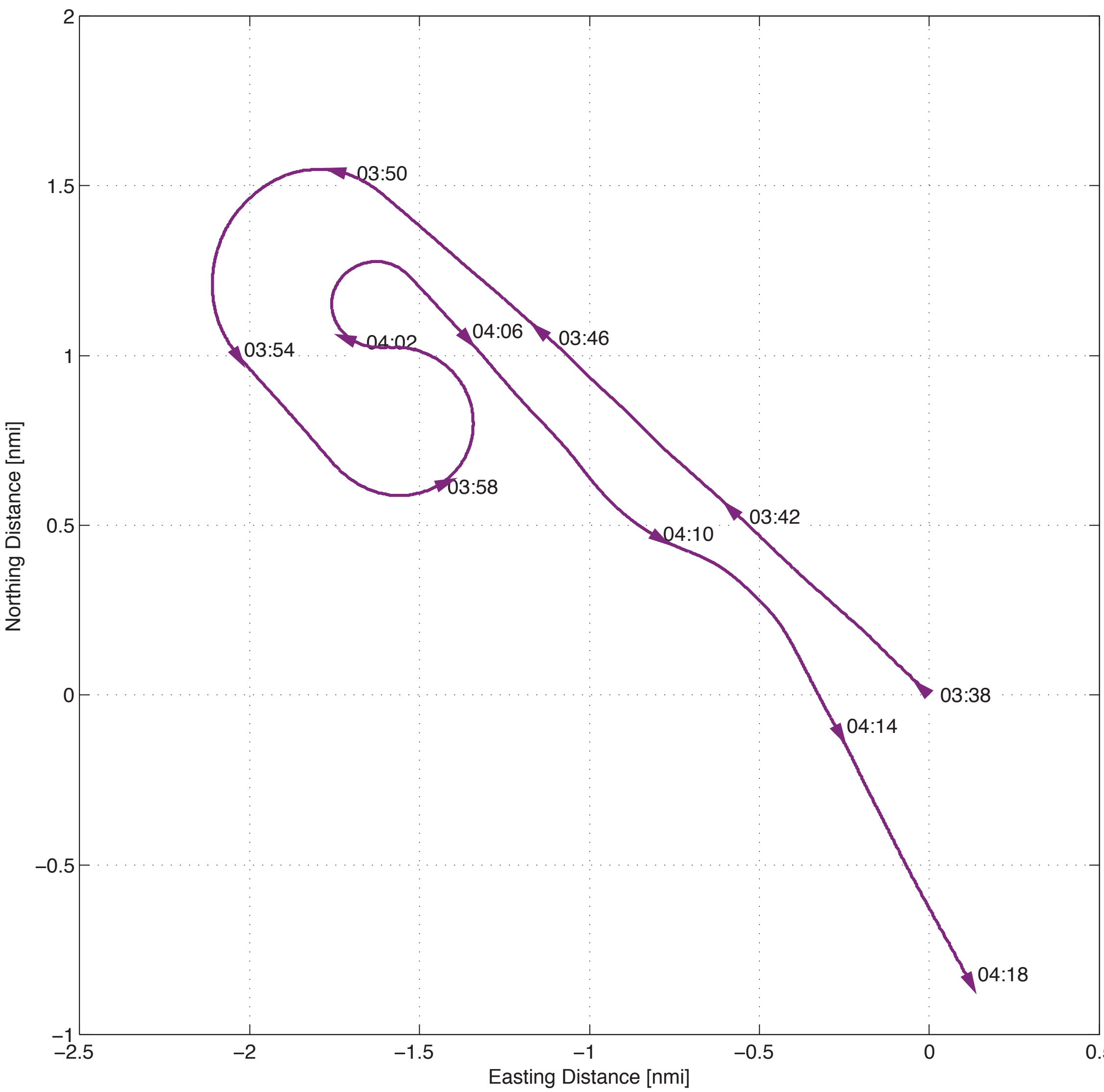

Figure 32: Ship track in vicinity of extreme pitch reading

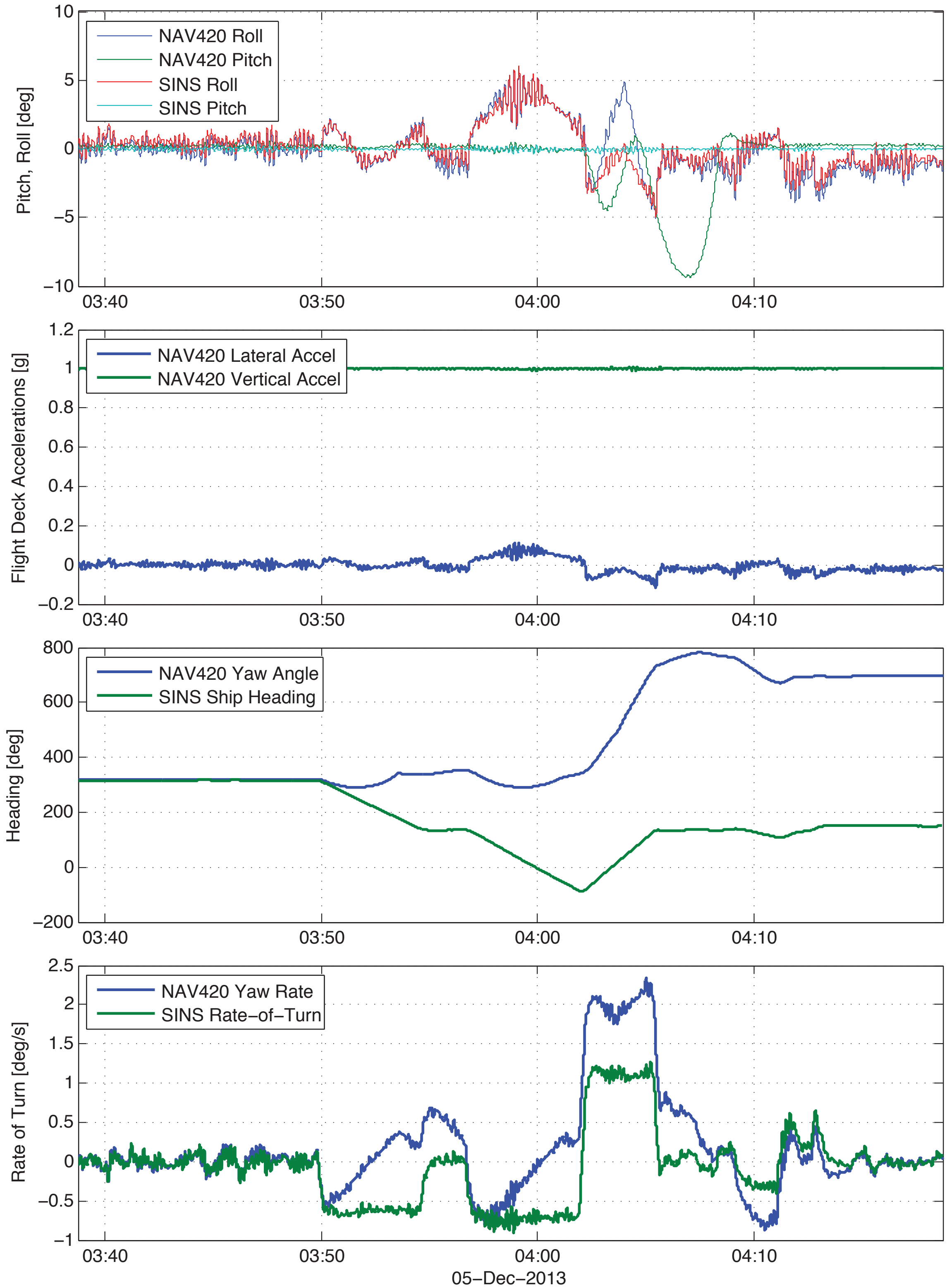

Figure 33: Ship motions in vicinity of extreme pitch reading

4.4 Wind data

Wind data was acquired by five separate sensors for this trial; three trial-fit anemometers (see Section 2.6), and the ship's existing port and starboard anemometers. An example of the relative wind data from all sensors is shown in Figure 35. These results were typical in that they show slightly different relative headings depending on the sensor location. This was particular true for the ship's sensors which, even at a 0° relative wind angle, showed differences of up to 10° between them. This behaviour was also seen to some degree in the wind tunnel testing and will be investigated further by NRC in a separate report.

True wind speed and direction was not measured directly, but calculated by subtracting the relative wind caused by the forward motion of the ship. Figure 36 shows the complete history of the true wind for the trial period as acquired from the NDDS using the ship's anemometers[8].

After the trial was complete and the bow pole was being taken down, it was noticed that the two aluminium supports were severely bent (see Figure 34). Early in the trial when sea states were higher, there were observed instances of waves hitting the pole. Some must have hit hard enough to bend the supports. There was no apparent damage to the sensors.

[8]True wind was calculated using the anemometer (port or starboard) which had the greatest largest absolute wind speed.

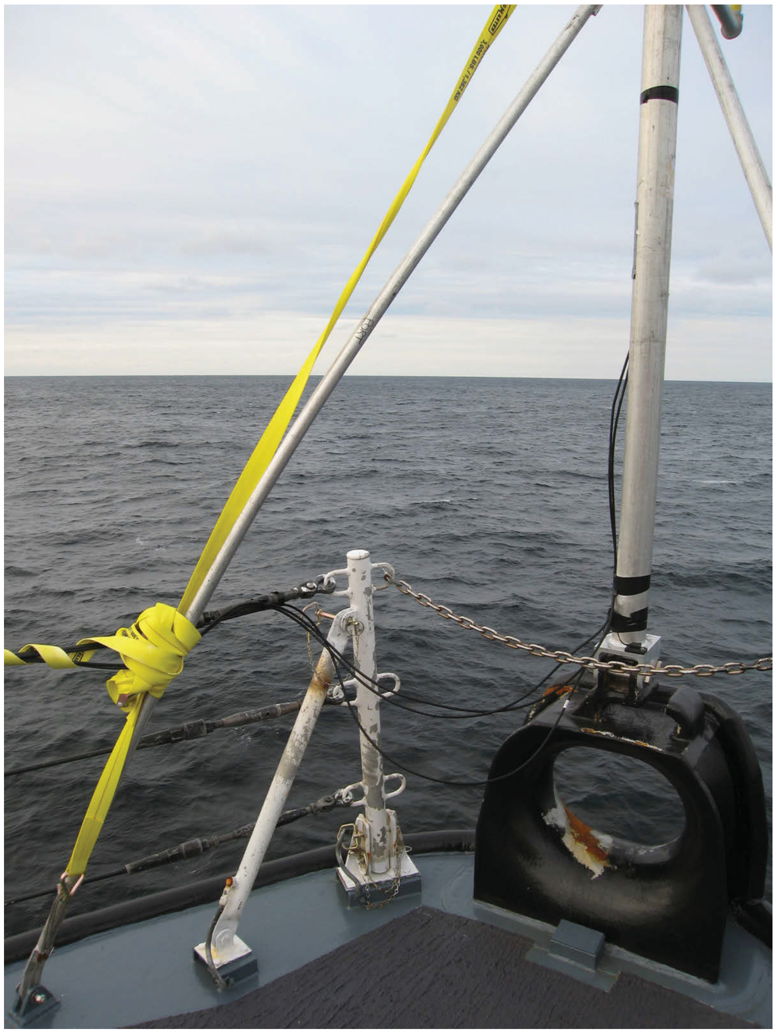

Figure 34: Bent bow pole support

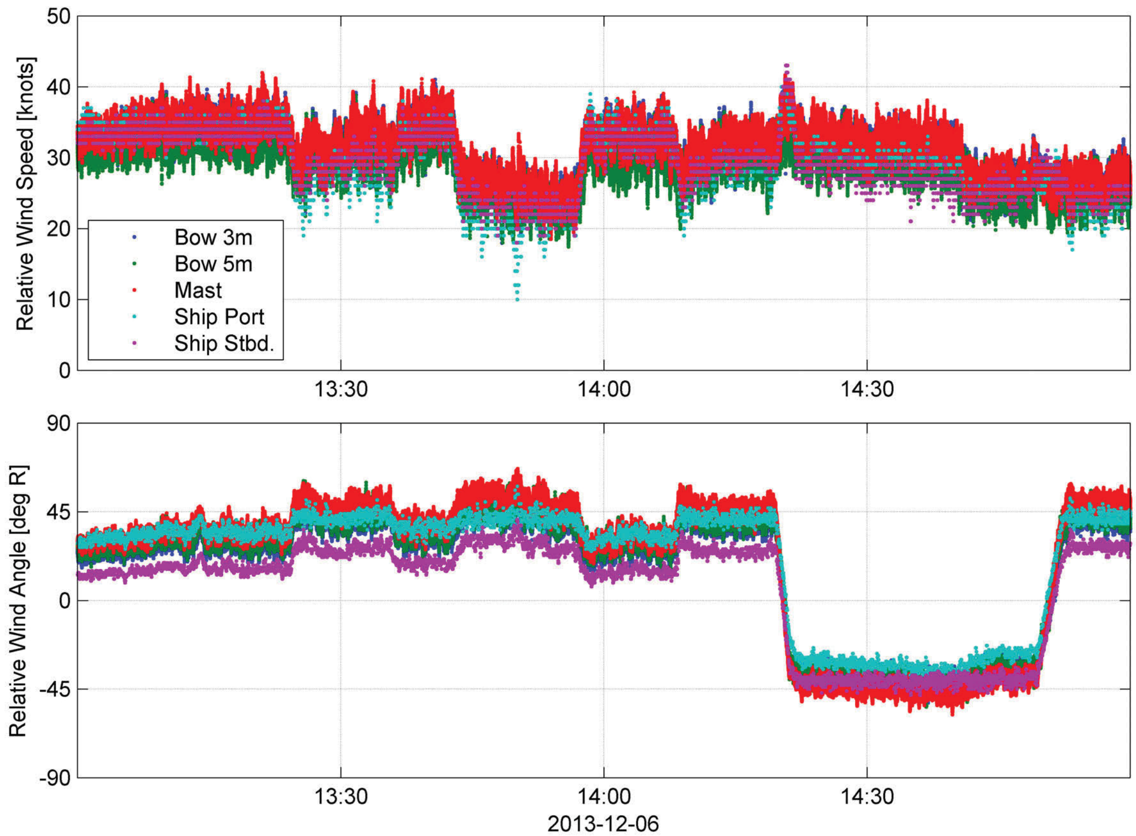

Figure 35: Sample of relative wind measurements

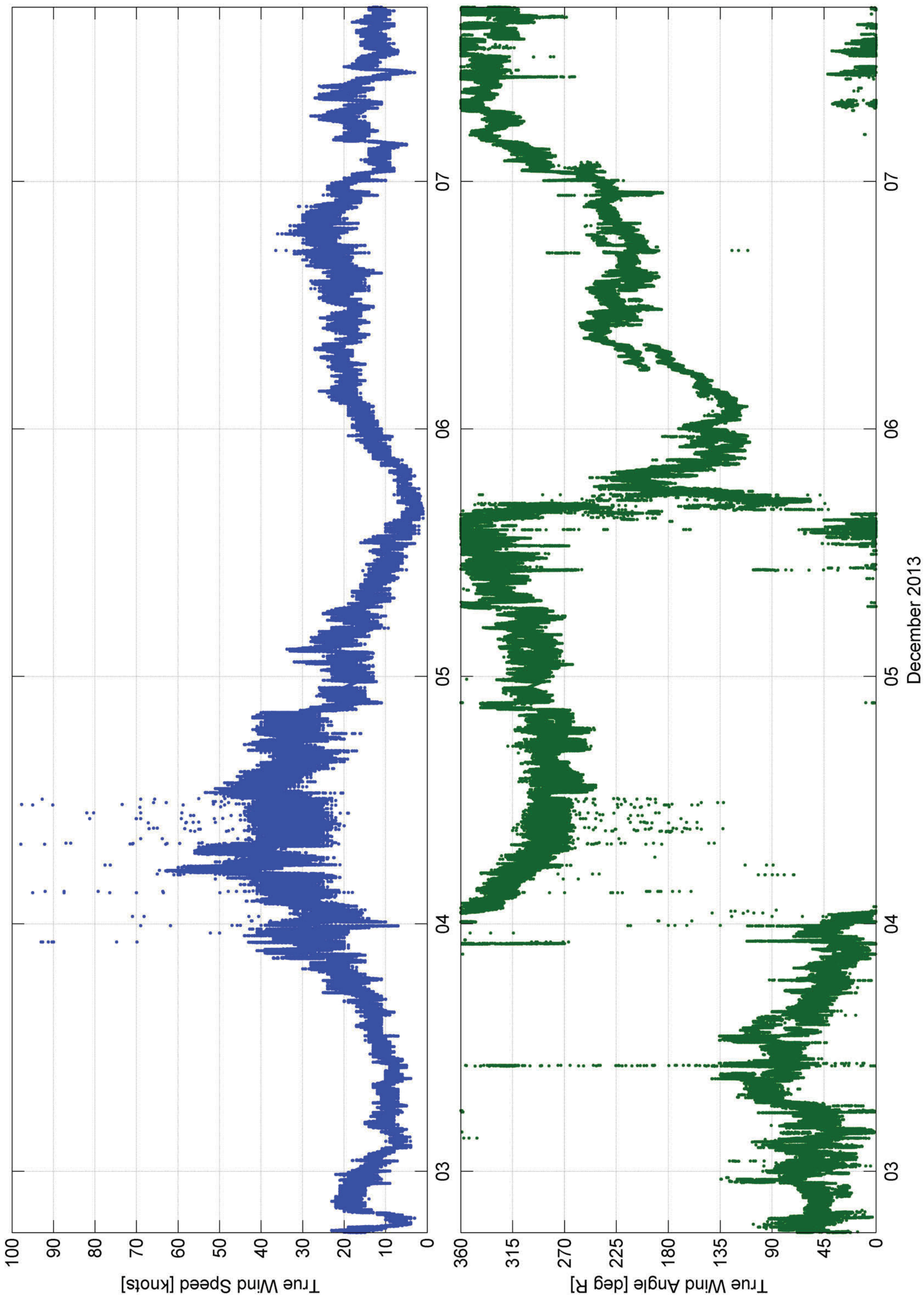

Figure 36: True wind measured by ship sensors

4.5 IPMS data

Data for the IPMS (see Section 2.2) was transferred to the DRDC team at the end of the trial. Unfortunately, port propeller pitch was not included in the set and could not be recovered from the ship system. Also, as the IPMS was not part of the DRDC network, it was not synchronized to the time signal used for the other data sets, but instead relied on its own internal clock. This clock had drift issues and was approximately 1 hour ahead of UTC during the trial. To compensate, time readings from the IPMS and the DRDC network were recorded periodically (at least once per day) so that the IPMS time could be corrected to UTC. These readings are given in Table 9.

Table 9: IPMS and UTC times

UTC	IPMS
2013-12-02 11:58:29	2013-12-02 13:02:30
2013-12-04 15:22:52	2013-12-04 16:26:55
2013-12-04 22:17:26	2013-12-04 23:21:32
2013-12-05 12:46:11	2013-12-05 13:50:20
2013-12-06 15:23:51	2013-12-06 16:28:05
2013-12-06 19:21:43	2013-12-06 20:25:57
2013-12-07 13:44:54	2013-12-07 14:49:12

4.6 Air temperature, humidity, and pressure

Meteorological data such as air temperature, humidity, and pressure were measured by the ship's sensors and by instruments brought specifically for this trial (see Section 2.7). The complete time histories for these measurements are shown in Figure 37. There was generally good agreement between the trail-fit and the ship's sensors except in the few cases where the trial-fit sensors show spikes or drop-outs. The cause of the temperature spikes in the trial-fit temperature sensor on 2013-12-06 is not known. The drop-outs on late 2013-12-02 and on 2012-12-05 occur in unison for all three trial-fit sensors. This was likely a fault of the data acquisition system and not the sensors themselves. Also, it was observed during the trial that the trial-fit humidity sensor failed (and was unrecoverable) at 2013-12-07 12:14 [UTC] for unknown reasons. It is believed that a times during the trial, the trial instruments became wet with sea spray generated by the bow in higher sea states. This may have caused some of the observed issues. On future trials, these sensors should be better sheltered.

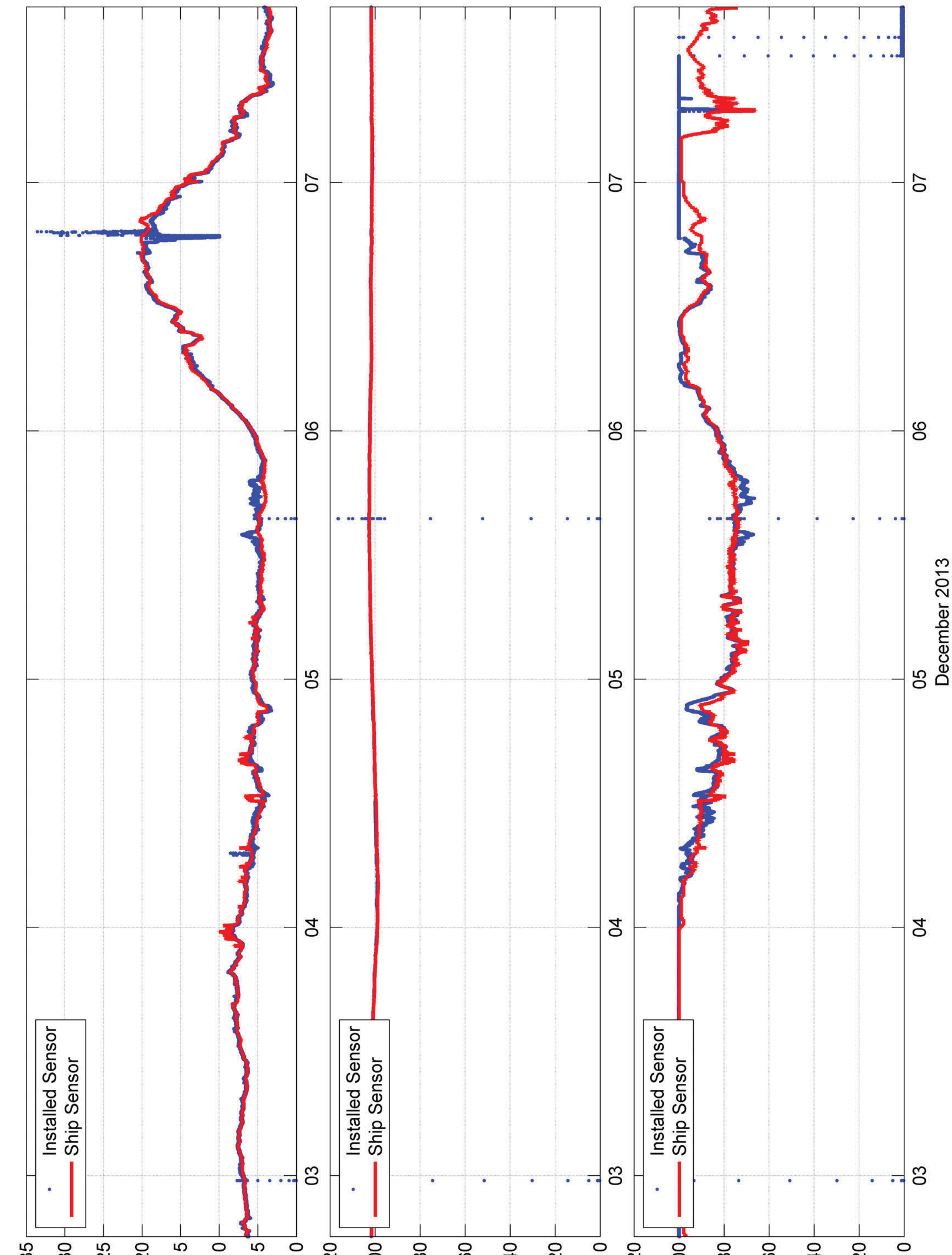

Figure 37: Air temperature, humidity, and pressure

4.7 MEDS buoys

A shown in Figure 27, the ship was, at times, in the vicinity of moored Marine Environmental Data Service (MEDS) buoys[9] which data log various environmental conditions such as wave heights and wind direction (see Table 11 for a full listing). Buoy data was retrieved from the National Buoy Data Center (NBDC) website (http://www.ndbc.noaa.gov/) after the trial.

Using the buoy locations listed Table 10, the distances to the ship were calculated for the trial ship track as shown in Figure 38. Figure 39 shows the Significant Wave Height (H_S) values recorded by the buoys. Also shown in the figure are the H_S values logged by the TOG Server (see Section 3) during the trial. These values were estimated by visual observation of the sea surface. Figure 40 shows the buoy-measured wind speeds.

Table 10: MEDS buoy locations

Buoy	Location
Station 44024 - N01 - Northeast Channel	42.312 N 65.927 W
Station 44150 - La Have Bank	42.505 N 64.018 W
Station 44137 - East Scotia Slope	42.234 N 62.018 W
Station 44258 - Halifax Harbour	44.502 N 63.403 W
Station 44011 (LLNR 825) - Georges Bank*	41.105 N 66.600 W

* Station 44011 went adrift on 9/8/2012.
Buoy was recovered 8/19/2013.

[9] Note that data from the Georges Bank buoy, coloured purple in Figure 27, was not available for the trial period.

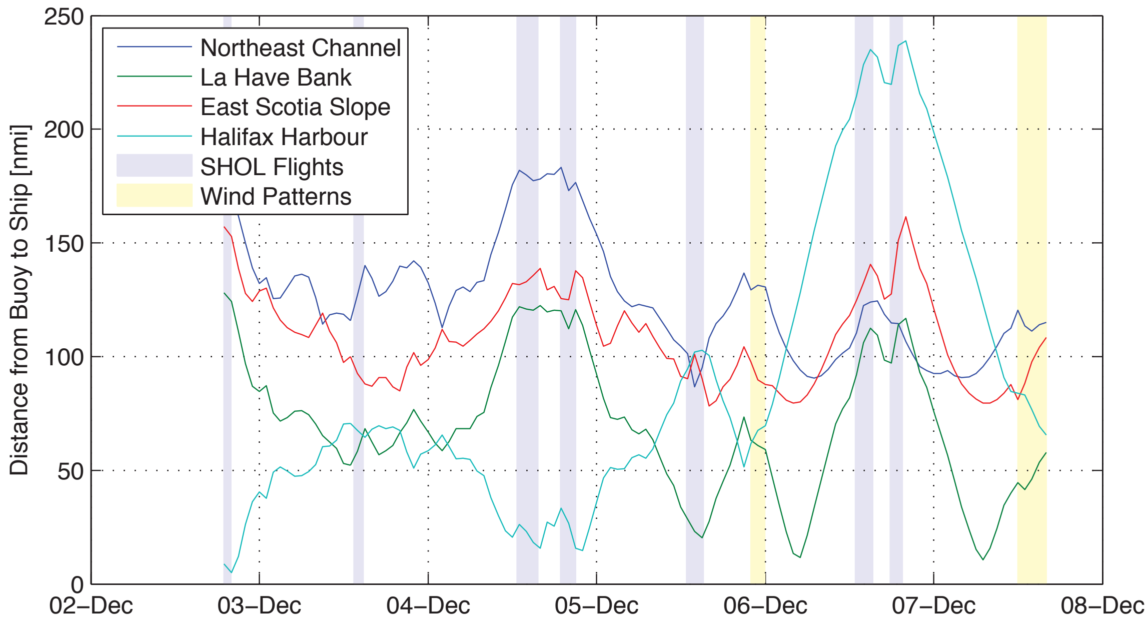

Figure 38: Distance from ship to moored meteorological buoys

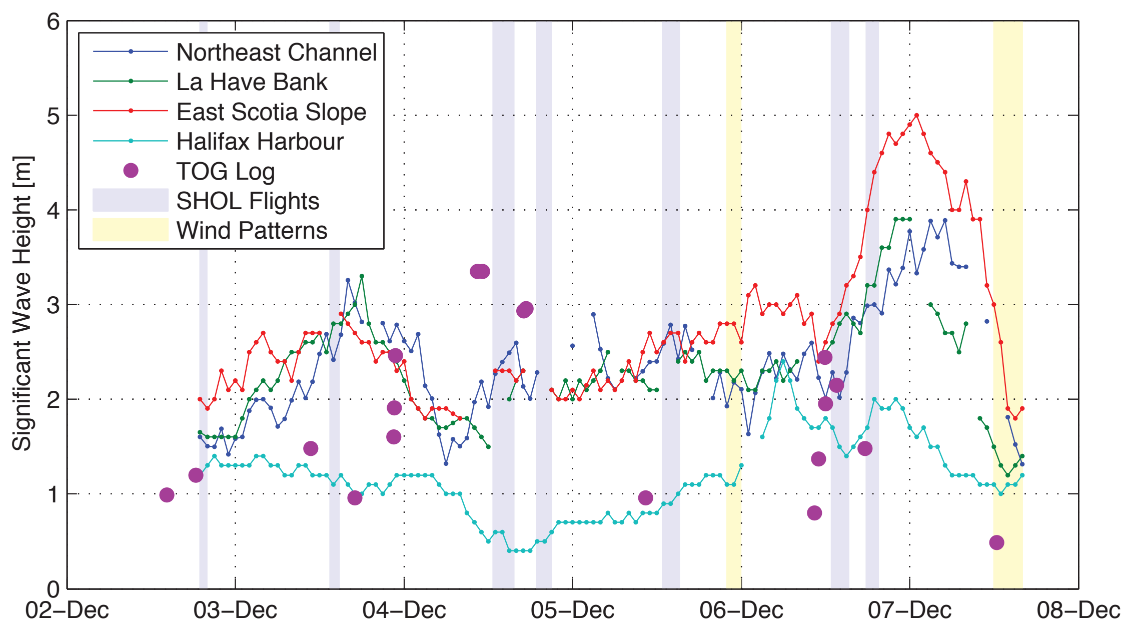

Figure 39: Wave heights from buoys and TOG

Table 11: MEDS buoy data set

Description	Units
Wind direction (the direction the wind is coming from in degrees clockwise from true North) during the same period used for Wind Speed.	deg. T
Wind speed averaged over an eight-minute period for buoys and a two-minute period for land stations. Reported Hourly.	m/s
Peak 5 or 8 second gust speed measured during the eight-minute or two-minute period.	m/s
Significant wave height is calculated as the average of the highest one-third of all of the wave heights during the 20-minute sampling period.	m
Dominant (Peak) wave period is the period with the maximum wave energy.	sec
Average wave period of all waves during the 20-minute period.	sec
The direction from which the waves at the dominant period (Tp) are coming. The units are degrees from true North, increasing clockwise, with North as 0 (zero) degrees and East as 90 degrees.	deg. T
Sea level atmospheric pressure.	hPa
Air temperature.	deg. C
Sea surface temperature.	deg. C
Dewpoint temperature taken at the same height as the air temperature measurement.	deg. C
Station visibility. Note that buoy stations are limited to reports from 0 to 1.6 nmi.	nmi
Pressure Tendency is the direction (plus or minus) and the amount of pressure change (hPa)for a three hour period ending at the time of observation.	hPa
The water level above or below Mean Lower Low Water (MLLW).	ft

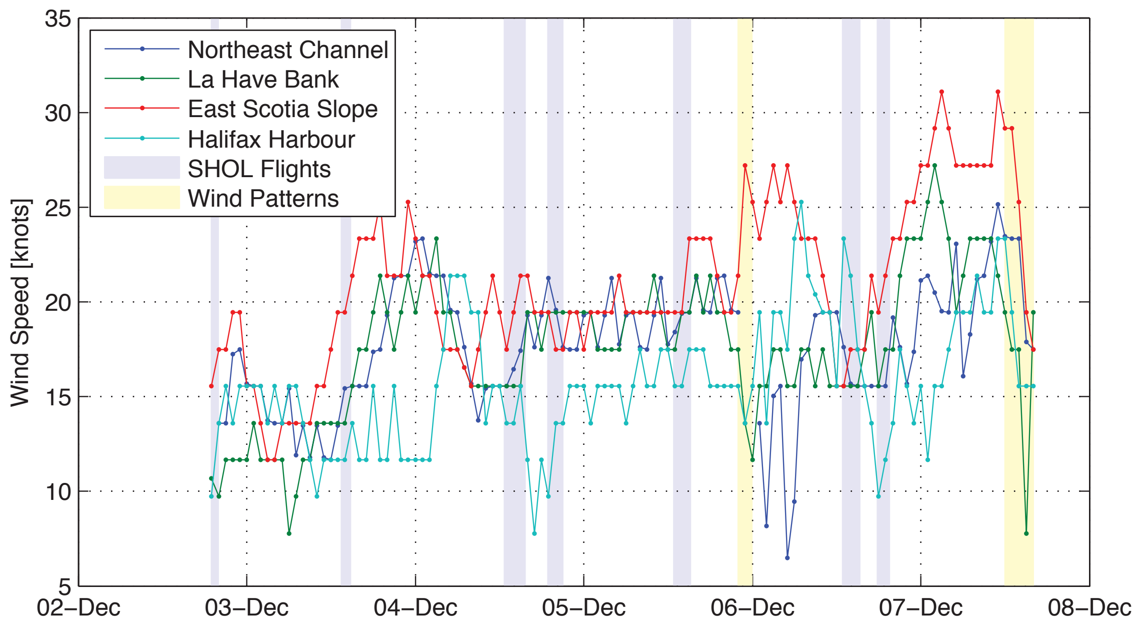

Figure 40: Wave speed from buoys

4.8 Summary data for AETE

After each of the trial activity periods (see Table 6), a summary file was generated by the DRDC team and given to the AETE team for analysis. The summary file included the ship and wind data feeds listed in Table 12. The individual data feeds were re-sampled (at 20 Hz) so that they would all share a common time reference. They were then combined and written to a tab-delimited ASCII file. No filtering, smoothing, or other processing was applied.

There was an issue in the summary files produced during the trial for data that was circular or period in nature. Circular data, such as azimuth angle or ship heading, wraps around a discontinuity (either through 360° to 0° or -180° to 180°) that causes problems with conventional analysis methods like linear interpolation which assumes continuous data. For example, given two data points 355° and 3°, the angle halfway between them is 359°. However, linear interpolation that does not account for wrapping would give an angle of 179°. When the trial data was initially re-sampled for the summary files, it used a standard linear interpolation method which caused errors whenever the wrapped data had a discontinuity. Similar errors would also be caused for conventional methods used for filtering/smoothing or for calculating quantities such as the mean, standard deviation, or median.

To correct for this problem, all of the AETE summary files were re-generated after the trial with functions that properly dealt with circular data (where applicable).

Table 12: AETE data summary variable list

Variable	Description	Units
GPS.TIME	GPS Date and Time	UTC
A1.UCOMP	Bow 3m Anemometer: u wind speed component	kts
A1.VCOMP	Bow 3m Anemometer: v wind speed component	kts
A1.WCOMP	Bow 3m Anemometer: w wind speed component	kts
A1.2DVEC	Bow 3m Anemometer: 2D (u-v) wind speed	kts
A1.AZIMU	Bow 3m Anemometer: Azimuth (2D direction)	deg R
A1.3DVEC	Bow 3m Anemometer: 3D wind speed	kts
A1.ELEVA	Bow 3m Anemometer: Elevation	deg
A1.SPDSO	Bow 3m Anemometer: Speed of Sound	kts
A1.TEMP	Bow 3m Anemometer: temperature	deg C
A2.UCOMP	Bow 5m Anemometer: u wind speed component	kts
A2.VCOMP	Bow 5m Anemometer: v wind speed component	kts
A2.WCOMP	Bow 5m Anemometer: w wind speed component	kts
A2.2DVEC	Bow 5m Anemometer: 2D (u-v) wind speed	kts
A2.AZIMU	Bow 5m Anemometer: Azimuth (2D direction)	deg R
A2.3DVEC	Bow 5m Anemometer: 3D wind speed	kts
A2.ELEVA	Bow 5m Anemometer: Elevation	deg

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Variable	Description	Units
A2.SPDSO	Bow 5m Anemometer: Speed of Sound	kts
A2.TEMP	Bow 5m Anemometer: temperature	deg C
A3.UCOMP	Mast Anemometer: u wind speed component	kts
A3.VCOMP	Mast Anemometer: v wind speed component	kts
A3.WCOMP	Mast Anemometer: w wind speed component	kts
A3.2DVEC	Mast Anemometer: 2D (u-v) wind speed	kts
A3.AZIMU	Mast Anemometer: Azimuth (2D direction)	deg R
A3.3DVEC	Mast Anemometer: 3D wind speed	kts
A3.ELEVA	Mast Anemometer: Elevation	deg
A3.SPDSO	Mast Anemometer: Speed of Sound	kts
A3.TEMP	Mast Anemometer: temperature	deg C
HC2.PRESS	Barometric Pressure 1	kPa
HC2.TEMP	Temperature 1	deg C
HC2.HUMD	Relative Humidity 1	%
S.PRESS	Ship Barometric Pressure	kPa
S.TEMP	Ship Temperature	deg C
S.HUMID	Ship Relative Humidity	%
GPS.LATT	GPS Latitude	deg
GPS.LONG	GPS Longitude	deg
S.HEADING	Ship Heading	deg T
S.COURSE	Ship Course	deg T
S.SPEED	Ship Speed	kts
NAV.PTCH	Ship Pitch Angle	deg
NAV.ROLL	Ship Roll Angle	deg
NAV.YAW	Ship Heading (Yaw Angle)	deg
NAV.PTRT	Ship Pitch Rate	deg/s
NAV.RLRT	Ship Roll Rate	deg/s
NAV.YWRT	Ship Yaw Rate	deg/s
NAV.XACC	Ship x-axis accel. at DLA	g
NAV.YACC	Ship y-axis accel. at DLA	g
NAV.ZACC	Ship z-axis accel. at DLA	g
S.AP.DIR	Port Anemometer Direction	deg R
S.AP.SPD	Port Anemometer Speed	kts
S.AS.DIR	Starboard Anemometer Direction	deg R
S.AS.SPD	Starboard Anemometer Speed	kts
S.AP.TRWDIR	Port Anemometer True Wind Direction	deg T
S.AP.TRWDSP	Port Anemometer True Wind Speed	kts
S.AS.TRWDIR	Starboard Anemometer True Wind Direction	deg T
S.AS.TRWDSP	Starboard Anemometer True Wind Speed	kts

5 Conclusions

The Halifax Class ships are in the process of a mid-life modernization. Upon completion, changes to the superstructure of the Halifax Class mean that the CH124 Ship-Helicopter Operational Limits will have to be re-certified for the post-refit Halifax Class. This report summarizes the activities of a sea trial conducted on HMCS FREDERICTON in support of this re-certification effort.

The trial was conducted from December 2-9, 2013. It involved the ship's crew, an Air Detachment (Air Det) from AETE, as well as scientific staff from DRDC and NRC. Both the ship and helicopter were instrumented with various sensors to acquire data needed for subsequent analysis of activities. A total of six test flights were performed in addition to two separate periods where the ship was dedicated to running patterns specifically for wind data analysis. The objectives of the trial were achieved. Analysis of the SHOL activities will be performed by AETE and analysis of the wind data will be performed by NRC.

The DRDC FDMS performed well and an additional "Event Logger" feature may be incorporated in a future version to help facilitate SHOL development activities. There were potential issues with the NAV420 motion sensor giving erroneous data during sharp turns. This will be investigated further. Other equipment, such as the supplementary anemometers and BMIS display functioned well. Overall this was a successful trial thanks to the well coordinated efforts of all involved.

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Annex A: Data gaps

This annex contains figures and tables showing gaps in the data acquired on this trial. The figures show blue dots for each gap larger than 1 second and red dots for any negative time steps (or overlapping data). Gaps that are too large to fit in the figure axes are identified with red arrows. Tables are given for each data set listing the gap size and times (for gaps larger than 5 seconds).

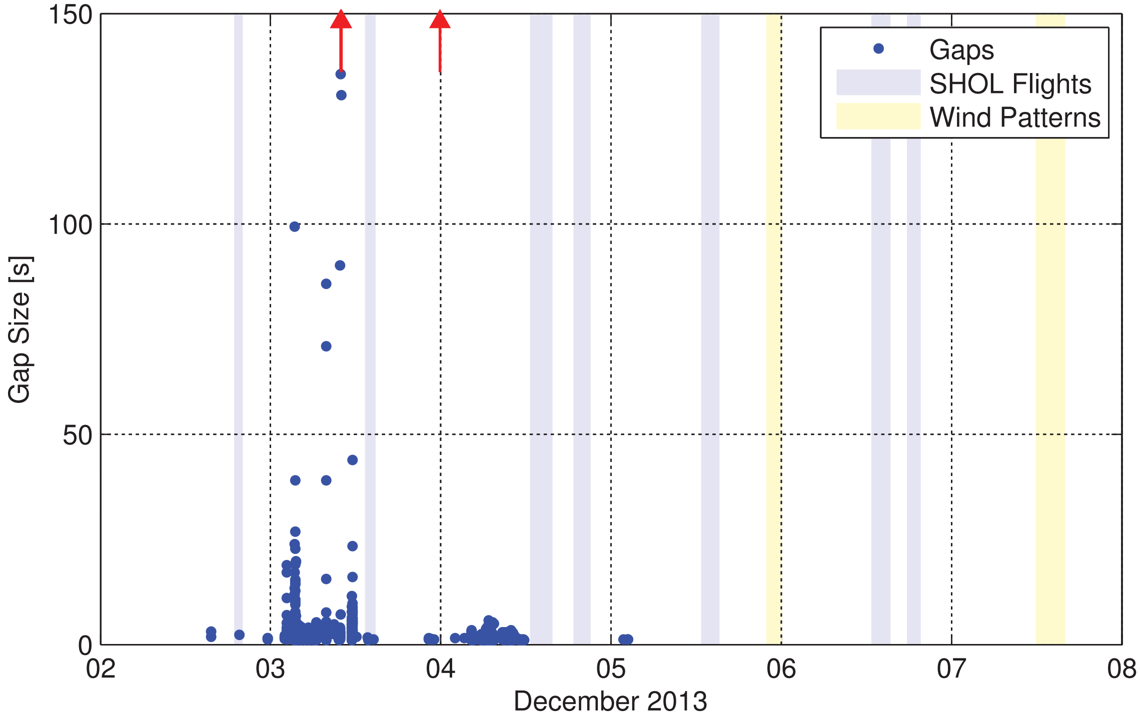

Figure A.1: Bow 3m anemometer data gaps

Table A.1: Data set bow 3m anemometer: gaps (>10s)

Gap [s]	Start Time	End Time
18.8	2013-12-03 02:16:07.439	2013-12-03 02:16:26.249
11.1	2013-12-03 02:16:33.499	2013-12-03 02:16:44.567
17.0	2013-12-03 02:16:44.567	2013-12-03 02:17:01.609
12.0	2013-12-03 03:24:30.291	2013-12-03 03:24:42.242
13.3	2013-12-03 03:24:49.369	2013-12-03 03:25:02.669
23.8	2013-12-03 03:25:02.756	2013-12-03 03:25:26.509
17.1	2013-12-03 03:25:33.689	2013-12-03 03:25:50.756
99.3	2013-12-03 03:25:51.313	2013-12-03 03:27:30.659
19.0	2013-12-03 03:27:36.740	2013-12-03 03:27:55.729
12.7	2013-12-03 03:27:56.752	2013-12-03 03:28:09.459
22.8	2013-12-03 03:28:23.549	2013-12-03 03:28:46.345
10.8	2013-12-03 03:28:51.239	2013-12-03 03:29:01.999
26.9	2013-12-03 03:29:03.169	2013-12-03 03:29:30.040
10.1	2013-12-03 03:29:36.125	2013-12-03 03:29:46.199
14.4	2013-12-03 03:30:21.042	2013-12-03 03:30:35.479
15.4	2013-12-03 03:30:51.379	2013-12-03 03:31:06.748
15.0	2013-12-03 03:31:11.921	2013-12-03 03:31:26.954
14.4	2013-12-03 03:31:27.730	2013-12-03 03:31:42.105
39.0	2013-12-03 03:32:20.207	2013-12-03 03:32:59.209
19.8	2013-12-03 03:32:59.322	2013-12-03 03:33:19.129
19.6	2013-12-03 03:33:24.574	2013-12-03 03:33:44.219
39.0	2013-12-03 07:51:03.438	2013-12-03 07:51:42.409
15.6	2013-12-03 07:51:42.719	2013-12-03 07:51:58.331
70.8	2013-12-03 07:51:58.331	2013-12-03 07:53:09.127
85.6	2013-12-03 07:53:09.127	2013-12-03 07:54:34.769
90.0	2013-12-03 09:50:00.179	2013-12-03 09:51:30.199
237.1	2013-12-03 09:51:30.199	2013-12-03 09:55:27.330
135.5	2013-12-03 09:55:34.459	2013-12-03 09:57:49.999
130.6	2013-12-03 09:57:49.999	2013-12-03 10:00:00.602
182.0	2013-12-03 10:00:00.602	2013-12-03 10:03:02.627
11.5	2013-12-03 11:29:28.129	2013-12-03 11:29:39.649
43.8	2013-12-03 11:31:13.492	2013-12-03 11:31:57.281
16.0	2013-12-03 11:33:52.349	2013-12-03 11:34:08.398
23.3	2013-12-03 11:34:26.189	2013-12-03 11:34:49.499
341.8	2013-12-03 23:52:59.399	2013-12-03 23:58:41.226

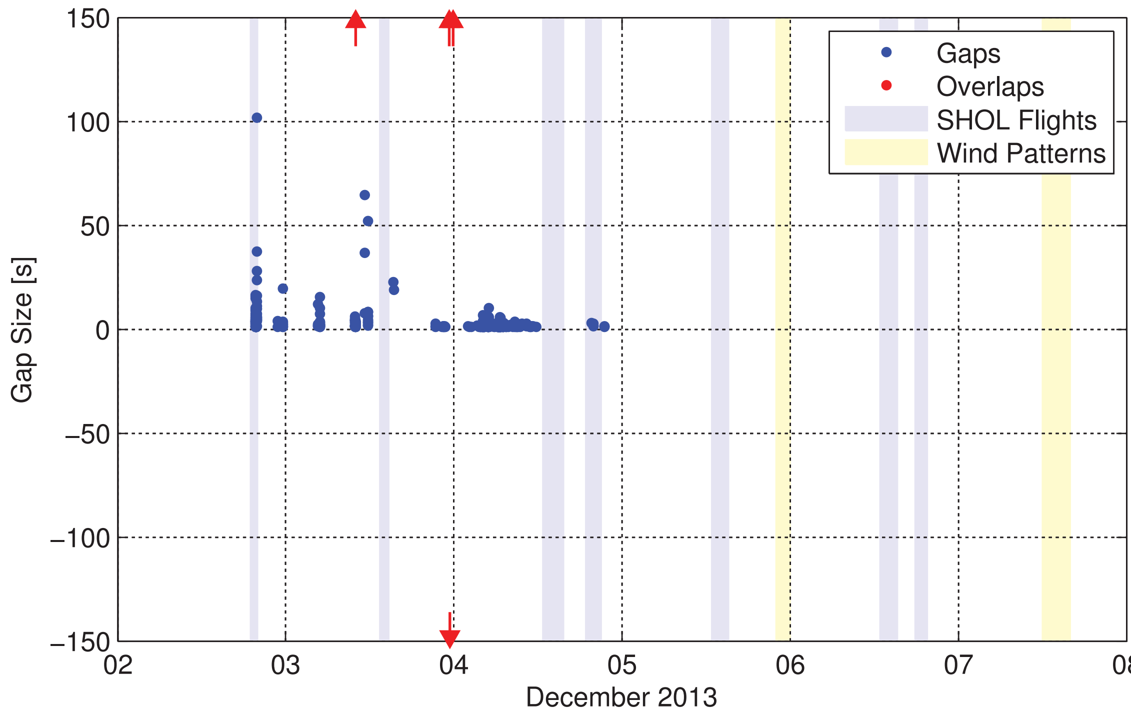

Figure A.2: Bow 5m anemometer data gaps

Table A.2: Data set bow 5m anemometer: gaps (>10s)

Gap [s]	Start Time	End Time
10.0	2013-12-02 19:40:13.785	2013-12-02 19:40:23.802
15.8	2013-12-02 19:40:26.458	2013-12-02 19:40:42.303
14.7	2013-12-02 19:41:15.548	2013-12-02 19:41:30.290
16.3	2013-12-02 19:42:15.051	2013-12-02 19:42:31.342
16.1	2013-12-02 19:51:09.212	2013-12-02 19:51:25.361
37.2	2013-12-02 19:51:25.361	2013-12-02 19:52:02.594
11.0	2013-12-02 19:52:02.594	2013-12-02 19:52:13.603
13.3	2013-12-02 19:52:23.582	2013-12-02 19:52:36.912
23.5	2013-12-02 19:52:53.192	2013-12-02 19:53:16.722
27.9	2013-12-02 19:53:16.840	2013-12-02 19:53:44.757
101.8	2013-12-02 19:53:44.757	2013-12-02 19:55:26.544
19.5	2013-12-02 23:34:15.302	2013-12-02 23:34:34.803
12.1	2013-12-03 04:34:34.158	2013-12-03 04:34:46.297
15.5	2013-12-03 04:53:11.712	2013-12-03 04:53:27.200
10.0	2013-12-03 04:54:55.029	2013-12-03 04:55:05.073
163.8	2013-12-03 09:59:59.992	2013-12-03 10:02:43.825
36.7	2013-12-03 11:17:43.669	2013-12-03 11:18:20.342
64.6	2013-12-03 11:18:20.342	2013-12-03 11:19:24.932
51.9	2013-12-03 11:46:35.742	2013-12-03 11:47:27.622
22.7	2013-12-03 15:23:08.909	2013-12-03 15:23:31.602
18.8	2013-12-03 15:25:10.102	2013-12-03 15:25:28.926
-341.1	2013-12-03 23:22:59.988	2013-12-03 23:17:18.887
244.8	2013-12-03 23:18:55.183	2013-12-03 23:23:00.019
338.0	2013-12-03 23:52:55.860	2013-12-03 23:58:33.885
10.2	2013-12-04 04:56:52.382	2013-12-04 04:57:02.576

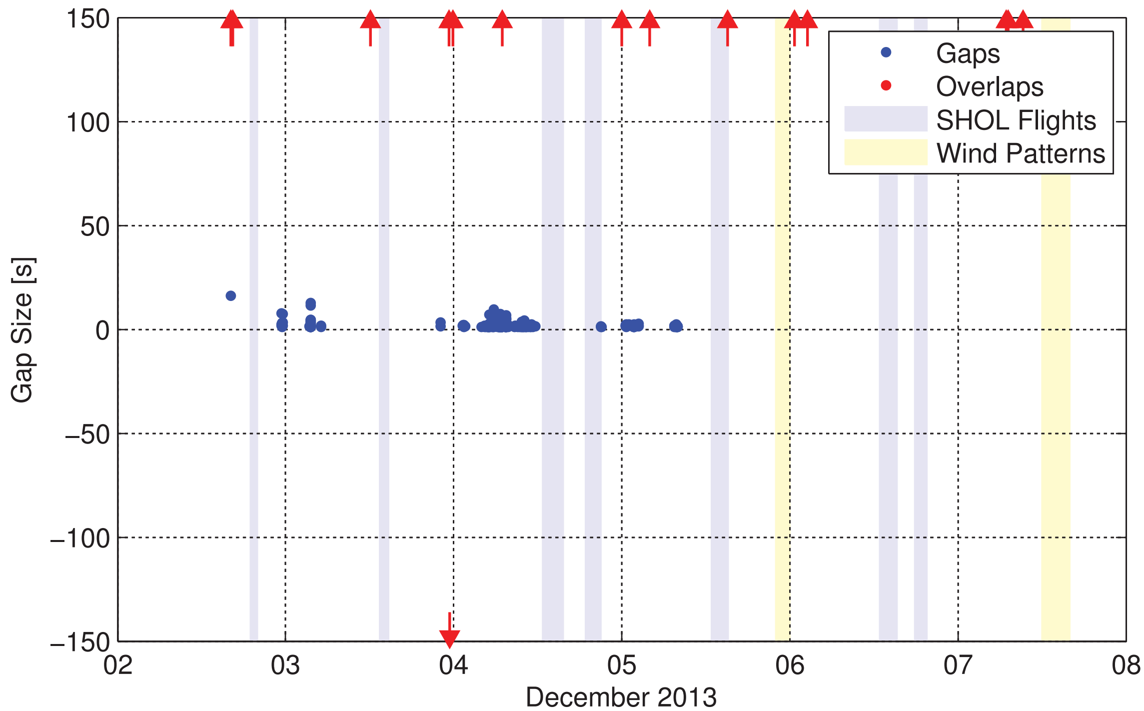

Figure A.3: Mast anemometer data gaps

Table A.3: Data set mast anemometer: gaps (>10s)

Gap [s]	Start Time	End Time
16.1	2013-12-02 16:08:20.372	2013-12-02 16:08:36.430
1,147.6	2013-12-02 16:08:36.430	2013-12-02 16:27:44.024
1,062.6	2013-12-02 16:30:01.360	2013-12-02 16:47:44.003
11.4	2013-12-03 03:32:49.292	2013-12-03 03:33:00.731
12.7	2013-12-03 03:33:46.025	2013-12-03 03:33:58.729
1,149.6	2013-12-03 12:08:34.454	2013-12-03 12:27:44.009
-638.4	2013-12-03 23:27:59.968	2013-12-03 23:17:21.526
540.3	2013-12-03 23:18:59.681	2013-12-03 23:28:00.008
357.5	2013-12-03 23:52:42.021	2013-12-03 23:58:39.559
1,143.7	2013-12-04 06:58:56.324	2013-12-04 07:18:00.039
760.1	2013-12-05 00:02:19.909	2013-12-05 00:15:00.025
979.5	2013-12-05 03:58:40.530	2013-12-05 04:14:59.999
1,163.2	2013-12-05 15:07:36.755	2013-12-05 15:26:59.999
364.8	2013-12-06 00:40:55.249	2013-12-06 00:47:00.025
1,115.8	2013-12-06 02:28:24.248	2013-12-06 02:47:00.004
700.1	2013-12-07 06:55:19.883	2013-12-07 07:07:00.019
997.1	2013-12-07 07:10:22.870	2013-12-07 07:27:00.004
480.0	2013-12-07 09:18:59.983	2013-12-07 09:27:00.016

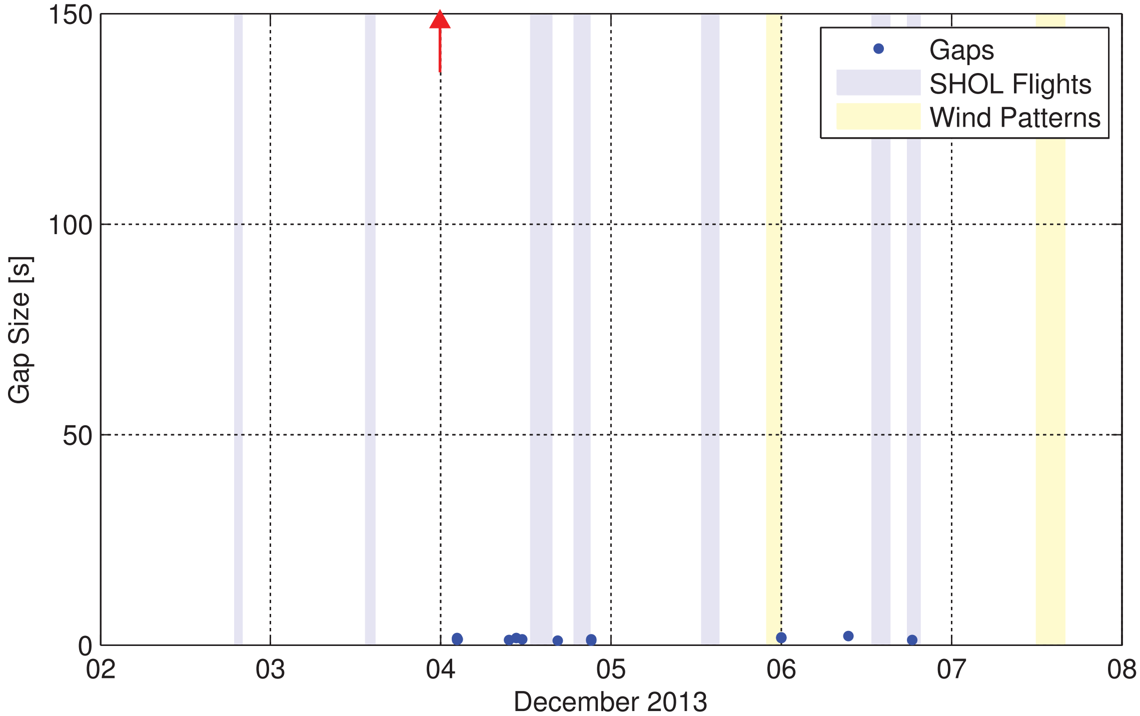

Figure A.4: Meteorological data gaps

Table A.4: Data set meteorological data: gaps (>10s)

Gap [s]	Start Time	End Time
230.2	2013-12-03 23:53:03.538	2013-12-03 23:56:53.691
124.8	2013-12-07 12:38:18.939	2013-12-07 12:40:23.757

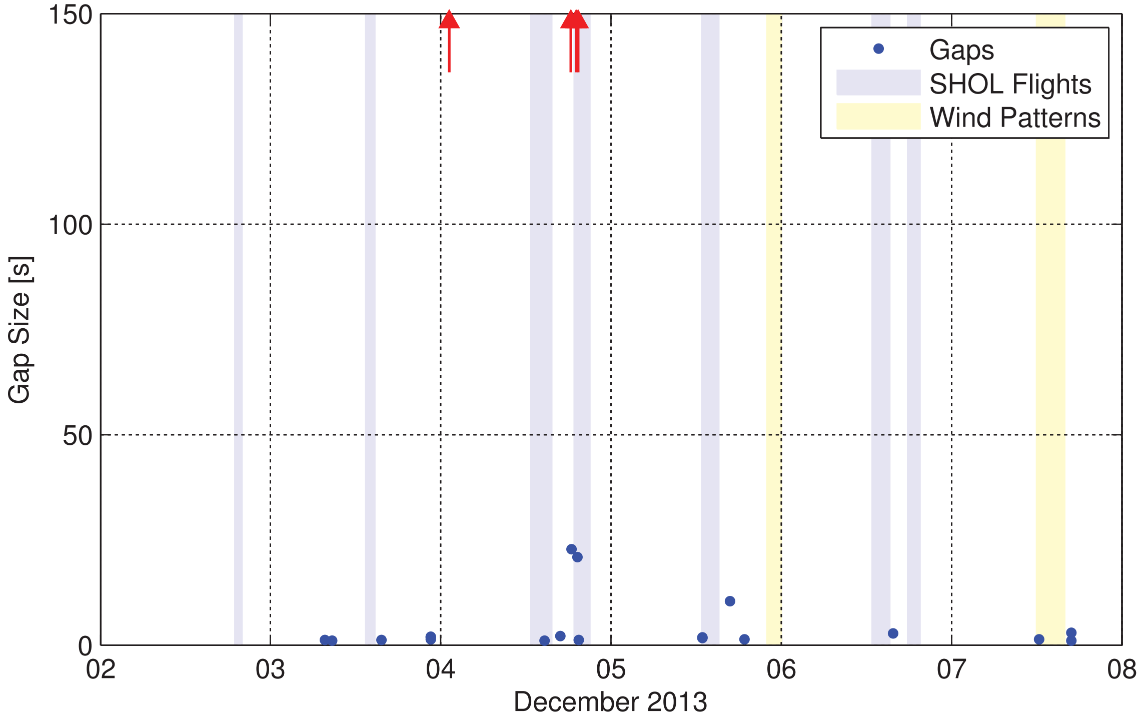

Figure A.5: NAV420 #0005012941 data gaps

Table A.5: Data set NAV420 #0005012941: gaps (>10s)

Gap [s]	Start Time	End Time
33,155.2	2013-12-04 01:09:49.335	2013-12-04 10:22:24.512
320.9	2013-12-04 18:20:15.066	2013-12-04 18:25:35.932
22.7	2013-12-04 18:25:35.932	2013-12-04 18:25:58.618
864.1	2013-12-04 19:04:14.683	2013-12-04 19:18:38.788
20.8	2013-12-04 19:18:38.788	2013-12-04 19:18:59.592
152.8	2013-12-04 19:19:17.208	2013-12-04 19:21:49.991
10.4	2013-12-05 16:49:26.134	2013-12-05 16:49:36.551

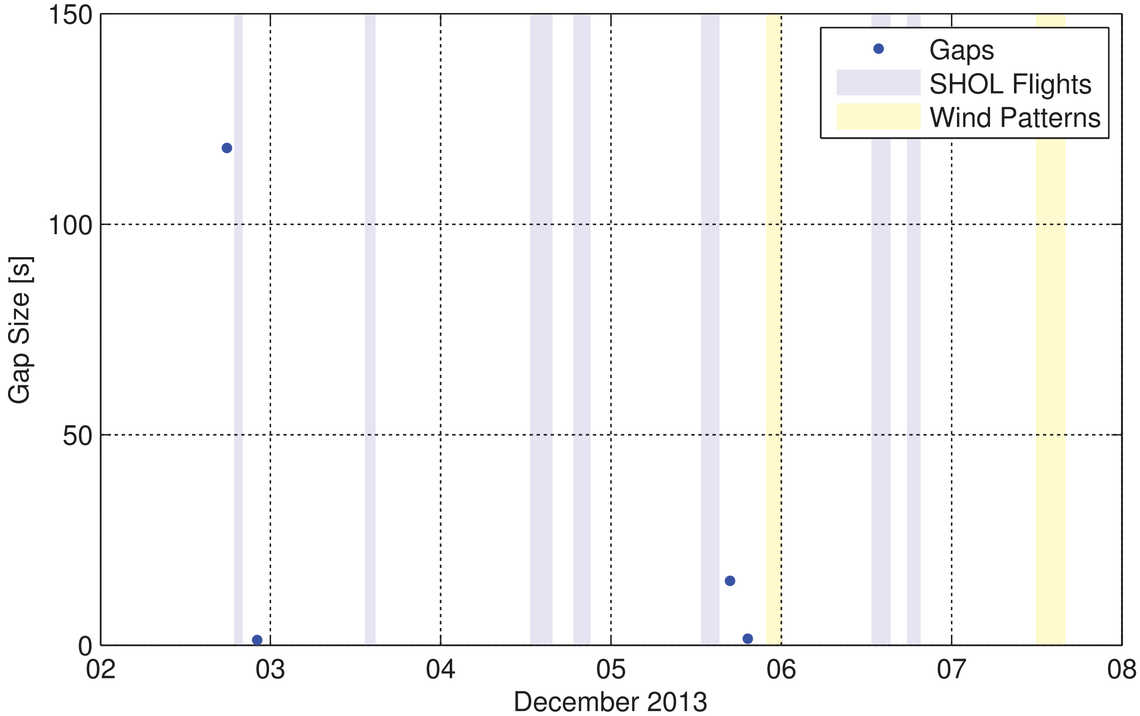

Figure A.6: NAV420 #05012937 data gaps

Table A.6: Data set NAV420 #05012937: gaps (>10s)

Gap [s]	Start Time	End Time
118.0	2013-12-02 17:52:15.032	2013-12-02 17:54:13.003
15.2	2013-12-05 16:46:20.851	2013-12-05 16:46:36.018

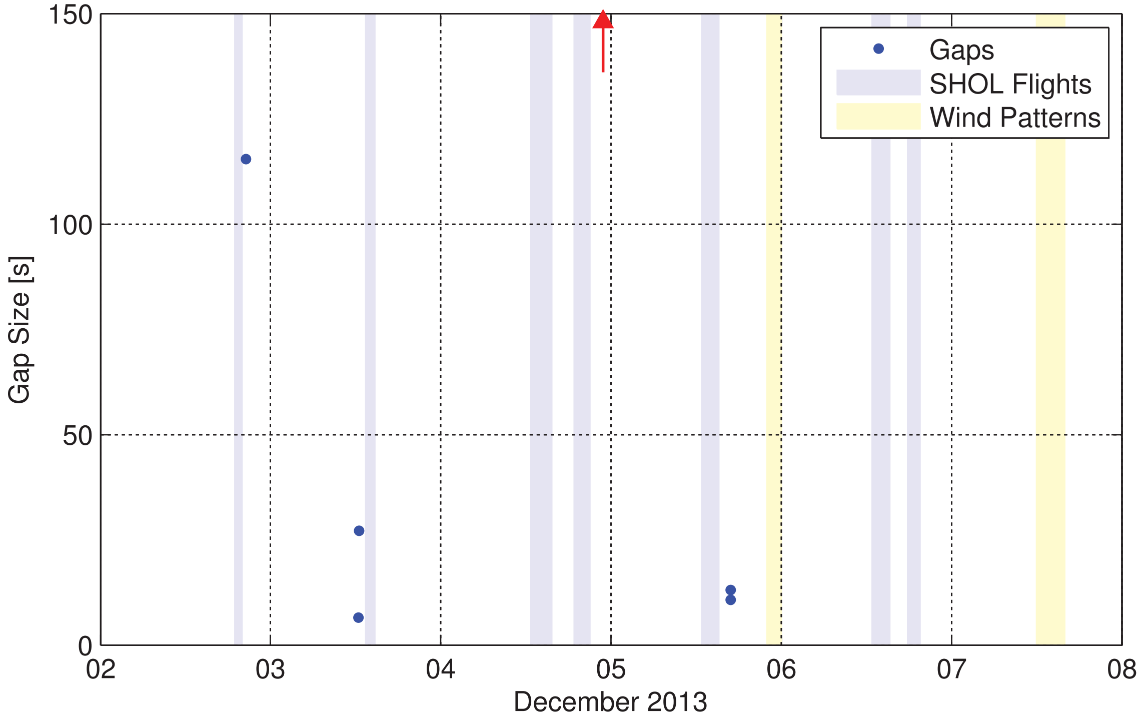

Figure A.7: NDDS data gaps

Table A.7: Data set NDDS: gaps (>10s)

Gap [s]	Start Time	End Time
115.3	2013-12-02 20:33:04.506	2013-12-02 20:34:59.834
27.1	2013-12-03 12:27:54.816	2013-12-03 12:28:21.894
1,971.9	2013-12-04 22:54:26.882	2013-12-04 23:27:18.818
10.8	2013-12-05 16:51:28.510	2013-12-05 16:51:39.260
13.1	2013-12-05 16:53:53.978	2013-12-05 16:54:07.041

Table A.8: Data set IPMS: gaps (>10s)

Gap [s]	Start Time	End Time
13,023.7	2013-12-06 15:18:42.243	2013-12-06 18:55:45.908

Acronyms

ADR	Air Detachment Room
AETE	Aerospace Engineering Test Establishment
Air Det	Air Detachment
a.k.a.	also known as
AP	Aft Perpendicular
ASCII	American Standad Code for Information Interchange
Aft SIS	Aft Sonar Integrated Space
BMIS	Bow-Mast Instrumentation System
C.G.	Centre of Gravity
CAD	Canadian Air Division
CFD	Computational Fluid Dynamics
COG	Course Over Ground
COMSEC	Communications Security
DAQ	Data Acquisition
DLA	Designated Landing Area
DND	Department of National Defence
DOF	Degrees of Freedom
DOP	Dilution of Precision
DRDC	Defence Research and Development Canada
EC	Engineering Change
FDCR	Flight Deck Control Room
FDMS	Flight Deck Motion System
FELEX	Frigate Life Extension
Flyco	Flight Deck Control Room
FMF Cape Scott	Fleet Maintenance Facility Cape Scott
FP	Forward Perpendicular
GHS	General Hydrostatics
GLM	GHS Load Monitor
GML	Vertical Distance from the C.G. to the Longitudinal Metacentre
GMT	Vertical Distance from the C.G. to the Transverse Metacentre
GPS	Global Positioning System
GT	Gas Turbine
HCI	Halifax Class IPMS
HCM	Halifax Class Modernization
HMCS	Her Majesty's Canadian Ship
H_S	Significant Wave Height
HTTP	Hypertext Transfer Protocol
IMU	Inertial Measurement Unit
IP	Internet Protocol
IPMS	Integrated Platform Management System

LAN	Local Area Network
LCG	Longitudinal Centre of Gravity
LGS	Landing Guidance Display
LSO	Landing Signals Officer
MCP	Major Capital Project
MDDS	Meteorological Data Distribution System
MEDS	Marine Environmental Data Service
MLLW	Mean Lower Low Water
MSP	Mode Selection Panel
MT	Metric Tonne
NBDC	National Buoy Data Center
NDDS	Navigational Data Distribution System
NI-DAQ	National Instruments Data Acquisition
NMEA	National Marine Electronics Association
nmi	Nautical Mile
NRC	National Research Council
NTP	Network Time Protocol
OAT	Outside Air Temperature
PDE	Propulsion Diesel Engine
PLA	Power Level Angle
PMSC	Protected Military Satellite Communication
QPI	Quiescent Period Indicator
RCN	Royal Canadian Air Force
RCN	Royal Canadian Navy
R&D	Research and Development
REST	Representational State Transfer
RMS	Root Mean Square
RPM	Rotations Per Minute
RTFD-OGS	Real-Time Flight Deck Operator Guidance System
RW	Relative Wind
SA	Situation Awareness
SA-OGS	Situation Awareness Operator Guidance System
SAM	SHOL Assessment Methodology
SHOL	Ship-Helicopter Operational Limits
SHOLAS	SHOL Analysis and Simulation
SINS	Ship Inertial Navigation System
SOG	Speed Over Ground
SS	Sea State
STW	Speed Through Water
TCG	Transverse Centre of Gravity
TOG	Tactical Operator Guidance
UDP	User Datagram Protocol

UK	United Kingdom
USB	Universal Serial Bus
UTC	Coordinated Universal Time
VCG	Vertical Centre of Gravity
WOD	Wind Over Deck
XML	Extensible Markup Language

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The Halifax Class frigates are in the process of a mid-life modernization. The engineering changes made to the ships during the refit have resulted in significant superstructure modifications affecting both the airwake over the flight deck and the accuracy of the mast-mounted anemometer system. This requires that the CH124 Sea King Ship-Helicopter Operational Limits (SHOL) envelope be re-certified for operation from post-refit ships. This re-certification will involve extensive wind tunnel experiments conducted by the National Research Council (NRC) in addition to a limited sea trial program. This report summarizes DRDC's contribution to the sea trial conducted on HMCS FREDERICTON in December 2013 that was part of this effort. The ship was instrumented with supplementary anemometers at the bow and mast to help validate the wind tunnel experiments. Aircraft operations were conducted by Aerospace Engineering Test Establishment (AETE) as part of the SHOL development with support from the prototype Flight Deck Motion System (FDMS) developed by DRDC Atlantic. Analysis and interpretation of the resulting data set is presented in separate reports by AETE and NRC.

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